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RESEARCH MEMORANDUM

THEORETICAL PERFORMANCE OF JP-4 FUEL WITH A 70-PERCENT-FLUORINE - 30-PERCENT-OXYGEN MIXTURE AS A ROCKET PROPELLANT

I - FROZEN COMPOSITION

By Sanford Gordon and Vearl N. Huff

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Theoretical rocket performance was calculated for JP-4 fuel with an oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight (fluorine-to-oxygen atom ratio of 2). Frozen composition was assumed during the expansion process. Data were calculated for two chamber pressures and for several pressure ratios and oxidant-fuel ratios.

The parameters included are specific impulse, combustion-chamber temperature, nozzle-exit temperature, molecular weight, characteristic velocity, coefficient of thrust, ratio of nozzle-exit area to throat area, specific heat at constant pressure, isentropic exponent, coefficient of viscosity, and coefficient of thermal conductivity. A correlation is given for the effect of chamber pressure on several of the parameters.

The maximum values of specific impulse for chamber pressures of 600 and 300 pounds per square inch absolute with an exit pressure of 1 atmosphere were 301.1 and 278.2 pound-seconds per pound, respectively.

INTRODUCTION

Liquid-fluorine - liquid-oxygen mixtures with JP-4 fuel have been considered recently as possible high-energy rocket propellants (refs. 1 to 5). Better performance may be obtained from hydrocarbon fuels with certain fluorine-oxygen mixtures than with either 100 percent fluorine or oxygen. The reason for this is that fluorine burns preferentially with hydrogen, and oxygen with carbon. This is fortunate in that the alternative formation of water instead of hydrogen fluoride would lead to lower combustion temperatures, and the formation of carbon tetrafluoride instead of carbon monoxide would lead to higher molecular weight. The result would then have been a lower ratio of temperature to molecular weight with a correspondingly lower performance.

According to data in reference 6, the optimum oxidant mixture with JP-4 fuel is about 70 percent fluorine and 30 percent oxygen by weight. Additional data were computed for JP-4 fuel with an oxidant containing 70.37 percent fluorine and 29.63 percent oxygen by weight (fluorine-to-oxygen atom ratio of 2) for both frozen and equilibrium composition during expansion. These data, which cover a wide range of oxidant-fuel ratios and pressure ratios, were calculated to aid in rocket design and for comparison with experimental results.

The present report presents the data obtained for two chamber pressures on the basis of frozen composition during expansion. A correlation is given which permits the determination of specific impulse, characteristic velocity, ratio of nozzle-exit area to throat area, combustion-chamber temperature, and nozzle-exit temperature for a wide range of chamber pressures.

SYMBOLS

The following symbols are used in this report:

A	nozzle area, sq in.
a	local velocity of sound (velocity of flow at throat), ft/sec
C_F	coefficient of thrust; $C_F = g_c I/c^* = F/P_c A_t$
C_p^o	molar specific heat at constant pressure, cal/(mole)(^{o}K)
c_p	specific heat at constant pressure, $\frac{\sum_i n_i (C_p^o)_i}{M(1 - n_k)}$, cal/(g)(^{o}K)
c_v	specific heat at constant volume
c^*	characteristic velocity, $g_c P_c A_t/w$, ft/sec
F	thrust, lb
$f_1, f_2, \ldots$	functions
g_c	gravitational conversion factor, $32.174 \left(\frac{\text{lb mass}}{\text{lb force}}\right)\left(\frac{\text{ft}}{\text{sec}^2}\right)$
H_T^o	sum of sensible enthalpy and chemical energy, cal/mole

h sum of sensible enthalpy and chemical energy per unit mass, $\frac{\sum_i n_i (H_T^o)_i}{M(1 - n_k)}$, cal/g

I specific impulse, lb force-sec/lb mass

k coefficient of thermal conductivity, cal/(sec)(cm)(^{o}K)

M molecular weight, $\frac{\sum_i n_i M_i}{1 - n_k}$, g/g-mole or lb/lb-mole

n mole fraction

n_{c^*} characteristic-velocity exponent, $\left(\frac{\Delta \log c^*}{\Delta \log P_c}\right)$

n_I specific-impulse exponent for fixed pressure ratio, $\left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{P_c/P}$

n_T temperature exponent for fixed pressure ratio, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{P_c/P}$

n_ε area-ratio exponent for fixed pressure ratio, $\left(\frac{\Delta \log \varepsilon}{\Delta \log P_c}\right)_{P_c/P}$

o/f oxidant-to-fuel weight ratio

P static pressure (sum of partial pressures), lb/sq in.

p partial pressure, lb/sq in.

R universal gas constant (consistent units)

r equivalence ratio, ratio of four times the number of carbon atoms plus the number of hydrogen atoms to two times the number of oxygen atoms plus the number of fluorine atoms, $\frac{4(C) + (H)}{2(O) + (F)}$

S_T^o	entropy at pressure of 1 atmosphere, cal/(mole)(^{o}K)
s	entropy per unit mass, $\dfrac{\sum_i n_i (S_T^o)_i}{M(1 - n_k)} - \dfrac{R \sum_j p_j \ln p_j/14.696}{PM}$, cal/(g)(^{o}K)
T	temperature, ^{o}K
w	mass-flow rate, lb/sec
γ	isentropic exponent, $\left(\dfrac{\partial \log P}{\partial \log \rho}\right)_s$
ε	ratio of nozzle area to throat area, A/A_t
ρ	density, lb/cu in.
μ	coefficient of viscosity, g/(cm)(sec) = poises

Subscripts:

c	combustion chamber
e	nozzle exit
i	product of combustion including both gaseous and solid phases
j	gaseous product of combustion
k	solid product of combustion (graphite)
o	conditions at 0^o K
P	constant pressure
P_c/P	constant pressure ratio
s	constant entropy
t	nozzle throat
1	reference point

CALCULATION OF PERFORMANCE DATA

Performance data were obtained for two chamber pressures for a range of equivalence ratios and pressure ratios. Frozen composition during expansion was assumed.

The computations were carried out by the method described in reference 7 with modifications to adapt it for use with an IBM card-programmed electronic calculator. The machine was operated with floating-decimal-point notation and eight significant figures. The successive approximation process used in the calculations was continued until seven-figure accuracy was reached in the desired values of the assigned parameters (mass balance and pressure).

Assumptions

The calculations were based on the following usual assumptions: perfect gas law, adiabatic combustion at constant pressure, isentropic expansion, no friction, homogeneous mixing, and one-dimensional flow. The products of combustion were assumed to be graphite and the following ideal gases: atomic carbon C, carbon monofluoride CF, carbon difluoride CF_2, carbon trifluoride CF_3, carbon tetrafluoride CF_4, difluoroacetylene C_2F_2, methane CH_4, carbon monoxide CO, carbon dioxide CO_2, atomic fluorine F, fluorine F_2, atomic hydrogen H, hydrogen H_2, hydrogen fluoride HF, water H_2O, atomic oxygen O, oxygen O_2, and the hydroxyl radical OH. The combustion products are assumed to be completely expanded within the exit nozzle; that is, ambient pressure equals exit pressure.

The graphite was assumed to be finely divided and in temperature and velocity equilibrium with the gases during the flow process.

Initial Data

Thermodynamic data. - The thermodynamic data for all combustion products except graphite, methane, the fluorocarbons, and water were taken from reference 7. Data for graphite were taken from reference 8, for carbon monofluoride from reference 9, for the remainder of the fluorocarbons from reference 10, and for water from reference 11. Data for methane were determined by the rigid-rotator - harmonic-oscillator approximation using spectroscopic data from reference 12. The base used in this report for assigning absolute values to enthalpy is the same as in reference 7.

The dissociation energy of fluorine was taken to be 35.6 kilocalories per mole and the heat of sublimation of graphite at 298.16° K was taken to be 171.698 kilocalories per mole (ref. 13). The heat of solution of oxygen and fluorine was taken to be zero.

Physical and thermochemical data. - The properties of the fuel used in these calculations are typical of the JP-4 fuel delivered to this laboratory over a period of 2 years. The JP-4 fuel was assumed to have a hydrogen-to-carbon weight ratio of 0.163 (atom ratio of 1.942), a lower heat of combustion value of 18,640 Btu per pound, and a specific gravity of 0.769. Additional properties of jet fuels may be found in reference 14.

The oxidant used in these calculations is a mixture containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight (fluorine-to-oxygen atom ratio of 2). Several properties of the oxidants taken from references 7, 13, 15, and 16 are listed in table I.

Viscosity data. - The viscosity data for the individual combustion products were either taken from the literature when available, or estimated. The viscosities of F, H, H_2, HF, N, and N_2 are given in reference 17. The viscosities of the remaining substances except H_2O were calculated using similar techniques. The viscosity of H_2O was obtained from a modified Sutherland equation (ref. 18).

Computation of Combustion Conditions

Combustion pressure was assigned (300 or 600 lb/sq in. abs). At this assigned pressure, the composition n_i; enthalpy h (including both chemical and sensible energy), and entropy s were determined for three temperatures at 100° K intervals. The temperatures were chosen to band the assigned value of enthalpy for the propellant mixture h_c. The formulas used to calculate h and s are (ref. 7)

$$h = \frac{\sum_i n_i (H_T^o)_i}{M(1 - n_k)} \tag{1}$$

$$s = \frac{\sum_i n_i (S_T^o)_i}{M(1 - n_k)} - \frac{1.98718 \sum_j p_j \ln p_j/14.696}{PM} \tag{2}$$

Combustion composition corresponding to h_c was obtained by ordinary three-point interpolation of composition as a function of h. Entropy s_c corresponding to h_c was obtained by means of a three-point three-slope interpolation of s as a function of h. The slope was obtained by means of the thermodynamic relation

$$\left(\frac{\partial s}{\partial h}\right)_P = \frac{1}{T} \tag{3}$$

It is convenient to treat the products of combustion (sometimes a mixture of solid graphite and ideal gases) as a single homogeneous fluid. Therefore, the molecular weight of the combustion products M is defined as the weight of a sample (including both gases and solid graphite) divided by the number of moles of gas, as given by the formula

$$M = \frac{\sum_i n_i M_i}{1 - n_k} \tag{4}$$

This value of M is suitable for use in the gas law

$$P = \frac{\rho RT}{M} \tag{5}$$

provided the solid phase is included in the density. Such a fluid will exhibit ideal properties as long as the volume of the gases is large with respect to the volume of the solid phase. This procedure is also consistent with the assumption that the solid particles are small enough to be considered gas molecules of extremely large molecular weight.

Computation of Exit Conditions

Calculation of parameters at assigned temperatures. - Exit temperatures were selected at 300° or 400° K intervals to cover the range of pressure ratios from 1 to 1500. At these selected temperatures, the following data were computed assuming isentropic expansion and frozen composition: pressure, enthalpy, specific heat at constant pressure, isentropic exponent, viscosity, thermal conductivity, nozzle area ratio, coefficient of thrust, and specific impulse.

Interpolation of throat pressure. - A cubic equation in terms of ln P was derived from the following function and its first derivative using the data at two assigned temperatures:

$$\text{function, } f_1 = \ln f_2 = \ln\left(\frac{h}{R} + \frac{\gamma T}{2M} - \frac{h_o}{R}\right)$$

$$\text{first derivative, } \frac{df_1}{d \ln P} = \frac{T}{2Mf_2}\left(\gamma + 1 + \frac{d\gamma}{d \ln P}\right)$$

(Values for $d\gamma/d \ln P$ were found by a numerical method.)

The two temperatures were selected to band the throat temperature. The pressure at the throat was found by interpolating $\ln P$ as a function of f_1 for the point $f_1 = \ln\left(\frac{h_c}{R} - \frac{h_o}{R}\right)$. At this point the velocity of flow equals the velocity of sound.

Interpolation of enthalpy. - Enthalpies were interpolated for a series of pressures including the throat pressure by means of quartic equations in terms of $\ln P$. Each of the quartic equations used was derived from data at two successive assigned temperatures and used to interpolate those points within the temperature interval. The data used in forming each quartic were the following function at one of the assigned temperatures and its first and second derivatives at both assigned temperatures:

$$\text{function, } f_3 = \frac{h}{R}$$

$$\text{first derivative, } \frac{df_3}{d \ln P} = \frac{T}{M}$$

$$\text{second derivative, } \frac{d^2 f_3}{(d \ln P)^2} = \frac{T}{M}\left(\frac{\gamma - 1}{\gamma}\right)$$

Interpolation of temperature. - Temperatures were interpolated for a series of pressures including the throat pressure by means of cubic equations in terms of $\ln P$. Each of the cubic equations used was derived from data at two successive assigned temperatures and used to interpolate those points within the temperature interval. The data used in forming each cubic were the following function and its first derivative at both assigned temperatures:

$$\text{function, } f_4 = \ln T$$

$$\text{first derivative, } \frac{df_4}{d \ln P} = \frac{\gamma - 1}{\gamma}$$

Interpolation of specific heat. - Specific heats were interpolated for a series of pressures including the throat pressure by means of cubic equations in terms of $\ln P$. Each of the cubic equations used was derived from values of specific heat for four successive temperatures and used to interpolate those points within the interval of the two middle temperatures.

Accuracy of interpolation. - The errors due to interpolation were checked for several cases. The values presented for enthalpy, entropy, and specific impulse appear to be correctly computed to all figures

tabulated, while the remaining parameters may in some cases be in error by one or two figures in the last place tabulated. However, because of uncertainties in the thermodynamic data used, all values are probably tabulated to more places than are entirely significant.

Formulas

The formulas used in computing the various performance parameters are as follows:

Specific impulse, lb force-sec/lb mass

$$I = 294.98\sqrt{\frac{h_c - h_e}{1000}} \tag{6}$$

Throat area per unit flow rate, (sq in.)(sec)/lb

$$\frac{A_t}{w} = \frac{2781.6\ T_t}{P_t M_t a} \tag{7}$$

Characteristic velocity, ft/sec

$$c^* = g_c P_c(A_t/w) = 32.174\ P_c(A_t/w) \tag{8}$$

Coefficient of thrust

$$C_F = \frac{g_c I}{c^*} = \frac{32.174\ I}{c^*} \tag{9}$$

Nozzle area per unit flow rate, (sq in.)(sec)/lb

$$\frac{A}{w} = \frac{86.455\ T}{PMI} \tag{10}$$

Ratio of nozzle-exit area to throat area

$$\varepsilon = \frac{A/w}{A_t/w} \tag{11}$$

Specific heat at constant pressure, cal/(g)(^{o}K)

$$c_p = \frac{\sum_i n_i (C_p^o)_i}{M(1 - n_k)} \tag{12}$$

Isentropic exponent

$$\gamma = \left(\frac{\partial \log P}{\partial \log \rho}\right)_s = \frac{c_p}{c_p - \frac{R}{M}} = \frac{c_p}{c_v} \tag{13}$$

(when the composition is frozen)

Coefficient of viscosity, poises

$$\mu = \frac{PM}{\sum_j \frac{p_j}{\mu_j/M_j}} \tag{14}$$

Coefficient of thermal conductivity, cal/(sec)(cm)($^{\circ}$K)

$$k = \mu\left(c_p + \frac{5}{4}\frac{R}{M}\right) \tag{15}$$

The values of viscosity and thermal conductivity for mixtures of combustion gases calculated by means of equations (14) and (15) are only approximate. When more reliable transport properties for the various products of combustion become available, a more rigorous procedure for computing the properties of mixtures may also be justified. When solid graphite was present among the combustion products, it was omitted from equation (14).

THEORETICAL PERFORMANCE DATA

Tables

The calculated values of the performance parameters are given in tables II to VI. The properties of gases in the combustion chamber and the characteristic velocity are given in table II for each chamber pressure and equivalence ratio. Table III presents the values of performance parameters at assigned temperatures and constant entropy. These values were computed directly and used to interpolate properties for assigned pressure ratios. The first temperature for each equivalence ratio is greater than the combustion temperature and represents an isentropic compression from combustion conditions. The data for this temperature were used for interpolation. The values of viscosity and thermal conductivity of the mixture are also given in this table as a function of temperature.

The performance parameters for small pressure ratios from 1 to 8 are given in table IV. These properties permit computations within the rocket

nozzle and for finite combustion-chamber diameters. Properties at the throat may be found where $\varepsilon = 1.000$. The values adjacent to the throat correspond to pressures which are 1.2 and 0.8 times the throat pressure.

The performance parameters for pressure ratios from 10 to 1500 are given in table V. This table gives sufficient data to permit interpolation of complete data for any pressure ratio within the range tabulated.

The specific-impulse and area-ratio values for expansion from chamber pressure to 1 atmosphere are summarized in table VI. The maximum values calculated for specific impulse for chamber pressures of 600 and 300 pounds per square inch absolute are 301.1 and 278.2, respectively, at 20.7 weight percent fuel. This mixture corresponds closely to the chemically correct mixture for the formation of carbon monoxide and hydrogen fluoride.

Curves

The performance parameters are plotted in figures 1 to 5 for chamber pressures of 600 and 300 pounds per square inch absolute.

Curves of specific impulse are presented in figure 1 for pressure ratios from 10 to 1500 as functions of weight percent fuel. The maximum values occur at about 20.5 weight percent fuel. The exponent n_I is also shown.

Curves of combustion temperature and exit temperature for pressure ratios from 10 to 1500 are plotted in figure 2 as functions of weight percent fuel. The exponent n_T is also shown.

Curves of the ratio of nozzle area to throat area are plotted in figure 3 for pressure ratios from 10 to 1500 as functions of weight percent fuel. The exponent n_ε is also shown.

Given in figure 4 are the curves for coefficient of thrust for pressure ratios from 10 to 1500 as functions of weight percent fuel.

Figure 5 presents curves of molecular weight and characteristic velocity as functions of weight percent of fuel. Also shown is the exponent n_{c^*}.

Effect of solid graphite. - The theoretical calculations of equilibrium composition in the combustion chamber showed that solid graphite was not present for the equivalence ratios of 1 to 1.6 (weight percent fuel, 14.83 to 21.79) and was present for equivalence ratios of 1.75 to

4.00 (weight percent fuel, 23.35 to 41.05). The appearance of solid graphite and carbon-fluorine compounds affected the values of the thermodynamic parameters and resulted in a break in the performance data in the region of 23 weight percent fuel. This break in the performance data is apparent in figures 1 to 5.

Chamber-Pressure Effect

According to data of reference 19, the logarithms of the parameters I, T, ε, and c^* are nearly linear with the logarithm of chamber pressure for a fixed equivalence ratio and pressure ratio. This linearity permits the data to be correlated by means of exponents according to the following equations:

$$n_I = \left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{P_c/P} \tag{16}$$

$$n_T = \left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{P_c/P} \tag{17}$$

$$n_\varepsilon = \left(\frac{\Delta \log \varepsilon}{\Delta \log P_c}\right)_{P_c/P} \tag{18}$$

$$n_{c^*} = \left(\frac{\Delta \log c^*}{\Delta \log P_c}\right) \tag{19}$$

Equations (16) to (19) may be written as

$$I = I_1\left(\frac{P_c}{P_{c,1}}\right)^{n_I} \tag{20}$$

$$T = T_1\left(\frac{P_c}{P_{c,1}}\right)^{n_T} \tag{21}$$

$$\varepsilon = \varepsilon_1\left(\frac{P_c}{P_{c,1}}\right)^{n_\varepsilon} \tag{22}$$

$$c^* = c_1^*\left(\frac{P_c}{P_{c,1}}\right)^{n_{c^*}} \tag{23}$$

where $P_{c,1}$ may be selected to be either 300 or 600 pounds per square inch absolute provided that I_1, T_1, ϵ_1, and c_1^* are the corresponding values for the chamber pressure selected.

The data of tables II and V were used in equations (16) to (19) to calculate exponents which are also shown in the tables and are plotted in figures 1, 2, 3, and 5.

To illustrate the use of these exponents, suppose it is desired to obtain the value of specific impulse for a chamber pressure of 450 pounds per square inch absolute and a pressure ratio of 30.62 (exit pressure, 1 atmosphere) for an equivalence ratio r of 1.5 (20.71 weight percent fuel). From figure 1(b) or table V(b), the value of I at this pressure ratio and equivalence ratio (but for a chamber pressure of 300 lb/sq in. abs) is 289.9 and the value of n_I is 0.0185. From equation (20),

$$I = 289.9 \left(\frac{450}{300}\right)^{0.0185}$$

$$= 289.9\ (1.0075)$$

$$= 292.1$$

A comparison of the parameters obtained by means of the chamber-pressure correlation and by a direct calculation for two examples is given in the following table (r = 1.5; 20.71 weight percent fuel):

Parameter	P_c, 450 lb/sq in. abs P_e, 1 atm			P_c, 1200 lb/sq in. abs P_e, 1 atm		
	Estimated by correlation	Direct calculation	Error	Estimated by correlation	Direct calculation	Error
I	292.08	292.12	0.04	320.61	320.53	0.08
T_c	4423.7	4424.1	.4	4616.0	4613.4	2.6
T_e	1910.9	1910.8	.1	1568.5	1567.4	1.1
ϵ	4.107	4.101	.006	7.956	7.948	.008
c^*	6505.8	6506.2	.4	6617.8	6615.9	1.9

It is expected that values estimated for other equivalence ratios and pressure ratios will have small errors of the order of magnitude shown in the previous table. A possible exception might occur when the value of the exponent is changing rapidly such as in the region when solid graphite first appears.

SUMMARY OF RESULTS

A theoretical investigation of the performance of JP-4 fuel with an oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight was made for the following conditions: (1) equivalence ratios from 1 to 4, (2) chamber pressures of 300 and 600 pounds per square inch, (3) pressure ratios from 1 to 1500, and (4) frozen composition during expansion.

The results of the investigation are as follows:

1. The maximum values of specific impulse for chamber pressures of 600 and 300 pounds per square inch absolute (40.83 and 20.41 atmospheres) and an exit pressure of 1 atmosphere were 301.1 and 278.2, respectively, at 20.7 weight percent fuel.

2. The data presented in this report permit interpolation of complete performance data for any equivalence ratio from 1.00 to 4.00, chamber pressure from 150 to 1200 pounds per square inch absolute, and pressure ratio up to 1500.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, January 23, 1956

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TABLE I. - PROPERTIES OF LIQUID OXIDANTS

Property	Oxygen, O_2	Fluorine, F_2
Molecular weight	32.00	38.00
Density, g/cc	[a]1.1415	[b]1.54
Freezing point, °C	[c]-218.76	[c]-217.96
Boiling point, °C	[c]-182.97	[c]-187.92
Enthalpy required to convert liquid at boiling point to gas at 25° C, kcal/mole	[d]3.080	[d]3.030
Enthalpy of vaporization, kcal/mole	[c,e]1.630	[c,f]1.51
Enthalpy of fusion, kcal/mole	[c,g].106	[c,h].372

[a]At -182.0° C; ref. 15.

[b]At -196° C; ref. 16.

[c]Ref. 13.

[d]Ref. 7.

[e]At -182.97° C.

[f]At -187.92° C.

[g]At -218.76° C.

[h]At -217.96° C.

TABLE II. - THERMODYNAMIC PROPERTIES OF GASES IN COMBUSTION CHAMBER FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Equivalence ratio, r, $\frac{4(C)+(H)}{2(O)+(F)}$	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Molecular weight, M	Enthalpy, h, cal/g (a)	Entropy, s, cal/(g)(°K)	Specific heat at constant pressure, c_p, cal/(g)(°K) (b)	Isentropic exponent, γ, $\left(\frac{\partial \log P}{\partial \log \rho}\right)_s$ (b)	Characteristic velocity exponent, n_{c^*}, $\left(\frac{\Delta \log c^*}{\Delta \log P_c}\right)$ (b)	Characteristic velocity, c^*, ft/sec (b)
Combustion-chamber pressure, 600 lb/sq in. abs											
14.83	5.743	1.00	4007	0.0354	22.24	2592.0	2.5230	0.365	1.324	0.0147	5974
19.60	4.102	1.40	4464	.0431	21.20	3064.9	2.6853	.397	1.309	.0174	6484
20.71	3.829	1.50	4479	.0434	20.95	3175.0	2.7138	.404	1.307	.0174	6539
21.79	3.589	1.60	4396	.0431	20.97	3282.1	2.7302	.414	1.297	.0172	6491
30.33	2.297	2.50	3898	.0319	20.41	4128.8	2.8100	.485	1.251	.0118	6277
Combustion-chamber pressure, 300 lb/sq in. abs											
14.83	5.743	1.00	3910	0.0354	22.10	2592.0	2.5851	0.364	1.328	0.0147	5913
17.87	4.595	1.25	4238	.0407	21.45	2893.9	2.6958	.384	1.318	.0165	6266
19.60	4.102	1.40	4332	.0431	21.03	3064.9	2.7505	.396	1.314	.0174	6406
20.71	3.829	1.50	4346	.0434	20.78	3175.0	2.7798	.403	1.311	.0174	6460
21.79	3.589	1.60	4267	.0431	20.80	3282.1	2.7962	.412	1.302	.0172	6414
23.35	3.282	1.75	4163	.0365	20.75	3437.3	2.8146	.426	1.290	.0135	6362
25.83	2.872	2.00	4067	.0354	20.55	3682.7	2.8399	.447	1.276	.0131	6344
30.33	2.297	2.50	3813	.0319	20.26	4128.8	2.8777	.484	1.254	.0118	6226
34.31	1.914	3.00	3552	.0264	20.04	4523.9	2.9025	.516	1.238	.0097	6070
41.05	1.436	4.00	3095	.0142	19.59	5192.5	2.9267	.565	1.219	.0053	5762

[a]The base used for enthalpy is given in reference 7.
[b]Parameter based on frozen composition.

TABLE III. - THEORETICAL PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion or compression]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(°K)	Coefficient of viscosity, μ, micropoises	Coefficient of thermal conductivity, k, cal/(sec)(cm)(°K)	Ratio of nozzle area to throat area, ϵ	Coefficient of thrust, C_F	Specific impulse, I, lb-sec/lb
r = 1.00 (14.83 percent fuel by weight)									
4400	880.19	2735.8	1.321	0.3678	1583	0.00076	------	--------	-------
4000	595.53	2589.3	1.324	.3648	1474	.00070	5.53	0.082	15.3
3600	388.09	2444.0	1.328	.3615	1361	.00064	1.03	.611	113.5
3200	241.56	2300.1	1.333	.3578	1246	.00058	1.04	.858	159.3
2800	141.97	2157.9	1.338	.3534	1126	.00052	1.27	1.047	194.3
2400	77.518	2017.5	1.345	.3480	1001	.00046	1.74	1.204	223.6
2000	38.374	1879.7	1.355	.3410	870	.00039	2.63	1.341	249.0
1600	16.561	1745.0	1.368	.3318	733	.00032	4.47	1.462	271.5
1200	5.801	1614.6	1.387	.3199	586	.00025	8.91	1.571	291.6
900	2.106	1520.1	1.405	.3099	466	.00020	17.58	1.645	305.4
600	.528	1428.5	1.422	.3010	336	.00014	44.90	1.714	318.2
r = 1.40 (19.60 percent fuel by weight)									
4800	816.82	3198.8	1.306	0.3999	1664	0.00086	------	-------	-------
4400	564.56	3039.6	1.310	.3961	1557	.00080	2.02	0.233	46.9
4000	378.05	2881.9	1.314	.3927	1449	.00074	1.02	.626	126.2
3600	243.66	2725.5	1.317	.3890	1337	.00068	1.04	.853	171.8
3200	149.84	2570.8	1.322	.3848	1222	.00061	1.25	1.029	207.4
2800	86.912	2417.8	1.328	.3798	1102	.00055	1.65	1.178	237.3
2400	46.773	2267.1	1.335	.3736	979	.00048	2.36	1.307	263.5
2000	22.792	2119.2	1.345	.3655	849	.00041	3.71	1.424	286.9
1600	9.671	1975.1	1.359	.3546	713	.00034	6.52	1.528	307.9
1200	3.329	1835.9	1.380	.3405	568	.00026	13.38	1.623	327.0
900	1.193	1735.6	1.399	.3286	451	.00020	26.93	1.688	340.1
600	.295	1638.6	1.417	.3185	324	.00014	70.08	1.748	352.3
r = 1.50 (20.71 percent fuel by weight)									
4800	806.49	3305.1	1.304	0.4074	1647	0.00087	------	--------	-------
4400	556.04	3142.9	1.307	.4035	1542	.00080	1.83	0.260	52.8
4000	371.36	2982.2	1.311	.4000	1434	.00074	1.01	.637	129.5
3600	238.65	2823.0	1.315	.3962	1324	.00068	1.05	.861	175.0
3200	146.31	2665.3	1.319	.3919	1209	.00062	1.27	1.036	210.6
2800	84.568	2509.6	1.325	.3868	1092	.00055	1.68	1.184	240.6
2400	45.339	2356.1	1.332	.3804	969	.00048	2.42	1.313	266.9
2000	21.998	2205.5	1.342	.3720	841	.00041	3.81	1.429	290.4
1600	9.289	2058.9	1.357	.3609	706	.00034	6.73	1.533	311.6
1200	3.180	1917.3	1.377	.3463	563	.00026	13.90	1.628	330.8
900	1.134	1815.3	1.397	.3340	447	.00020	28.11	1.693	344.0
600	.279	1716.7	1.415	.3234	321	.00014	73.57	1.753	356.2
r = 1.60 (21.79 percent fuel by weight)									
4400	602.43	3283.7	1.297	0.4136	1497	0.00080	------	-------	-------
4000	398.17	3119.1	1.301	.4098	1393	.00074	1.03	0.590	119.1
3600	253.04	2955.9	1.305	.4057	1286	.00067	1.04	.835	168.5
3200	153.25	2794.6	1.309	.4011	1176	.00061	1.24	1.021	206.0
2800	87.418	2635.2	1.315	.3956	1061	.00055	1.66	1.176	237.3
2400	46.181	2478.2	1.322	.3889	943	.00048	2.41	1.311	264.5
2000	22.038	2324.4	1.332	.3800	818	.00041	3.85	1.431	288.7
1600	9.130	2174.6	1.346	.3683	688	.00033	6.92	1.539	310.4
1200	3.055	2030.2	1.367	.3531	548	.00026	14.59	1.636	330.0
900	1.067	1926.2	1.386	.3402	435	.00020	30.11	1.703	343.5
600	.256	1825.9	1.405	.3288	312	.00014	80.83	1.764	356.0
r = 2.50 (30.33 percent fuel by weight)									
4000	682.17	4178.2	1.250	0.4868	1570	0.00096	-------	-------	-------
3600	404.11	3984.6	1.254	.4809	1447	.00087	1.04	0.574	112.0
3200	226.76	3793.6	1.258	.4743	1321	.00079	1.08	.876	170.8
2800	118.92	3605.3	1.264	.4668	1190	.00070	1.44	1.094	213.4
2400	57.201	3420.4	1.270	.4577	1055	.00061	2.20	1.273	248.3
2000	24.541	3239.5	1.279	.4460	913	.00052	3.82	1.426	278.2
1600	8.984	3064.1	1.292	.4307	765	.00042	7.62	1.560	304.4
1200	2.593	2895.7	1.311	.4102	607	.00032	18.40	1.679	327.6
900	.793	2775.2	1.330	.3927	480	.00025	43.10	1.759	343.2
600	.161	2660.2	1.353	.3734	343	.00017	135.7	1.832	357.5

TABLE III. - Continued. THEORETICAL PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion or compression]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(°K)	Coefficient of viscosity, μ, micropoises	Coefficient of thermal conductivity, k, cal/(sec)(cm)(°K)	Ratio of nozzle area to throat area, ε	Coefficient of thrust, C_F	Specific impulse, I, lb-sec/lb
r = 1.00 (14.83 percent fuel by weight)									
4000	328.90	2624.7	1.327	0.3645	1477	0.00070	------	--------	------
3600	214.96	2479.5	1.331	.3613	1365	.00065	1.08	0.538	98.9
3200	134.22	2335.7	1.336	.3576	1248	.00059	1.02	.813	149.3
2800	79.161	2193.5	1.341	.3533	1128	.00053	1.21	1.013	186.2
2400	43.393	2053.2	1.348	.3479	1003	.00046	1.63	1.178	216.5
2000	21.578	1915.4	1.358	.3410	872	.00040	2.44	1.320	242.6
1600	9.362	1780.7	1.372	.3318	734	.00033	4.11	1.446	265.7
1200	3.300	1650.3	1.391	.3200	587	.00025	8.11	1.557	286.2
900	1.205	1555.8	1.408	.3101	467	.00020	15.88	1.634	300.3
600	.304	1464.1	1.425	.3014	337	.00014	40.22	1.705	313.3
r = 1.25 (17.87 percent fuel by weight)									
4400	350.51	2956.1	1.316	0.3854	1576	0.00079	------	--------	------
4000	236.18	2802.7	1.320	.3821	1466	.00073	1.18	0.457	89.1
3600	153.24	2650.5	1.324	.3785	1353	.00067	1.00	.747	145.5
3200	94.935	2499.9	1.329	.3746	1236	.00061	1.13	.951	185.2
2800	55.513	2351.0	1.334	.3698	1116	.00054	1.44	1.116	217.3
2400	30.146	2204.2	1.341	.3639	991	.00048	2.02	1.258	245.0
2000	14.839	2060.1	1.351	.3562	860	.00041	3.11	1.383	269.3
1600	6.368	1919.6	1.366	.3460	723	.00033	5.36	1.495	291.2
1200	2.220	1783.8	1.386	.3327	576	.00026	10.79	1.596	310.8
900	.804	1685.6	1.405	.3216	458	.00020	21.42	1.665	324.2
600	.201	1590.6	1.422	.3122	329	.00014	54.92	1.729	336.7
r = 1.40 (19.60 percent fuel by weight)									
4400	320.11	3091.7	1.313	0.3963	1555	0.00080	------	--------	-------
4000	214.99	2933.8	1.317	.3929	1447	.00074	1.08	0.536	106.8
3600	138.99	2777.4	1.320	.3893	1335	.00068	1.01	.794	158.2
3200	85.770	2622.4	1.325	.3852	1220	.00061	1.18	.986	196.2
2800	49.937	2469.3	1.331	.3802	1101	.00055	1.53	1.143	227.6
2400	26.986	2318.4	1.338	.3741	978	.00048	2.16	1.280	254.9
2000	13.211	2170.3	1.348	.3661	849	.00041	3.36	1.401	279.0
1600	5.635	2025.9	1.362	.3554	713	.00034	5.85	1.510	300.7
1200	1.951	1886.5	1.383	.3414	568	.00026	11.90	1.608	320.2
900	.703	1785.8	1.402	.3297	451	.00020	23.77	1.676	333.6
600	.175	1688.5	1.420	.3196	324	.00014	61.37	1.738	346.1
r = 1.50 (20.71 percent fuel by weight)									
4400	315.85	3196.5	1.310	0.4038	1539	0.00081	------	--------	-------
4000	211.58	3035.7	1.314	.4003	1432	.00074	1.07	0.548	110.1
3600	136.41	2876.3	1.318	.3966	1322	.00068	1.02	.803	161.2
3200	83.916	2718.5	1.322	.3923	1208	.00062	1.19	.993	199.3
2800	48.689	2562.6	1.328	.3873	1090	.00055	1.55	1.150	230.8
2400	26.213	2408.9	1.335	.3809	968	.00048	2.20	1.286	258.2
2000	12.778	2258.1	1.345	.3727	841	.00041	3.44	1.407	282.5
1600	5.424	2111.1	1.359	.3617	706	.00034	6.03	1.515	304.3
1200	1.868	1969.2	1.380	.3473	563	.00026	12.33	1.613	323.9
900	.670	1866.9	1.399	.3351	447	.00020	24.77	1.680	337.4
600	.166	1768.0	1.418	.3246	321	.00014	64.30	1.743	349.9
r = 1.60 (21.79 percent fuel by weight)									
4400	342.74	3337.2	1.300	0.4137	1498	0.00080	------	--------	-------
4000	227.29	3172.5	1.304	.4099	1394	.00074	1.13	0.490	97.6
3600	144.97	3009.3	1.308	.4059	1287	.00068	1.01	.773	154.1
3200	88.148	2847.8	1.312	.4014	1177	.00061	1.17	.975	194.4
2800	50.498	2688.3	1.318	.3959	1062	.00055	1.53	1.140	227.3
2400	26.806	2531.3	1.325	.3892	944	.00048	2.19	1.282	255.6
2000	12.860	2377.2	1.335	.3805	819	.00041	3.47	1.408	280.6
1600	5.360	2227.2	1.350	.3690	689	.00034	6.16	1.520	303.0
1200	1.806	2082.5	1.370	.3539	549	.00026	12.87	1.621	323.1
900	.635	1978.3	1.389	.3411	436	.00020	26.34	1.690	336.8
600	.153	1877.7	1.408	.3298	313	.00014	70.06	1.754	349.6

TABLE III. - Concluded. THEORETICAL PERFORMANCE AT ASSIGNED EXIT TEMPERATURES FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion or compression.]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute.

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(°K)	Coefficient of viscosity, μ, micropoises	Coefficient of thermal conductivity, k, cal/(sec)(cm)(°K)	Ratio of nozzle area to throat area, ϵ	Coefficient of thrust, C_F	Specific impulse, I, lb-sec/lb
r = 1.75 (23.35 percent fuel by weight)									
4400	384.18	3538.7	1.288	0.4287	1478	0.00081	------	-------	-------
4000	251.27	3368.0	1.291	.4245	1376	.00075	1.30	0.393	77.6
3600	157.88	3199.1	1.295	.4201	1270	.00069	1.00	.728	144.0
3200	94.453	3032.1	1.300	.4151	1161	.00062	1.14	.950	187.8
2800	53.154	2867.1	1.305	.4093	1049	.00055	1.49	1.126	222.7
2400	27.661	2704.8	1.313	.4021	931	.00049	2.17	1.277	252.5
2000	12.977	2545.8	1.322	.3928	809	.00041	3.50	1.408	278.5
1600	5.270	2391.0	1.336	.3805	680	.00034	6.36	1.526	301.7
1200	1.721	2241.9	1.356	.3645	542	.00026	13.66	1.631	322.5
900	.588	2134.6	1.375	.3508	431	.00020	28.73	1.703	336.7
600	.137	2031.3	1.395	.3381	309	.00014	79.08	1.769	349.8
r = 2.00 (25.83 percent fuel by weight)									
4400	432.25	3832.2	1.273	0.4509	1576	0.00090	------	-------	-------
4000	277.80	3652.7	1.277	.4463	1465	.00083	1.80	0.259	51.1
3600	171.28	3475.2	1.281	.4414	1351	.00076	1.00	.682	134.4
3200	100.38	3299.6	1.285	.4360	1234	.00069	1.12	.926	182.6
2800	55.222	3126.5	1.290	.4296	1113	.00061	1.48	1.116	220.0
2400	28.014	2956.1	1.297	.4218	987	.00054	2.18	1.275	251.4
2000	12.766	2789.3	1.307	.4118	856	.00046	3.60	1.414	278.8
1600	5.012	2627.2	1.320	.3985	718	.00037	6.74	1.537	303.1
1200	1.573	2471.1	1.340	.3809	571	.00029	15.04	1.647	324.7
900	.518	2359.1	1.359	.3659	452	.00022	32.76	1.721	339.4
600	.116	2251.6	1.381	.3508	324	.00015	94.16	1.790	352.9
r = 2.50 (30.33 percent fuel by weight)									
4000	380.10	4219.5	1.252	0.4870	1572	0.00096	------	-------	--------
3600	226.01	4025.9	1.256	.4811	1449	.00087	1.11	0.489	94.6
3200	127.33	3834.7	1.261	.4746	1323	.00079	1.04	.827	160.0
2800	67.071	3646.3	1.266	.4672	1192	.00070	1.35	1.059	204.9
2400	32.416	3461.2	1.272	.4581	1056	.00061	2.03	1.246	241.0
2000	13.982	3280.2	1.281	.4466	914	.00052	3.48	1.404	271.7
1600	5.150	3104.4	1.294	.4314	766	.00042	6.89	1.543	298.6
1200	1.497	2935.7	1.313	.4111	608	.00032	16.46	1.665	322.2
900	.460	2815.0	1.332	.3937	481	.00025	38.25	1.747	338.1
600	.094	2699.7	1.355	.3744	343	.00017	119.4	1.822	352.6
r = 3.00 (34.31 percent fuel by weight)									
3600	321.49	4548.5	1.238	0.5165	1508	0.00097	-------	-------	--------
3200	174.87	4343.3	1.242	.5090	1376	.00087	1.00	0.664	125.4
2800	88.626	4141.4	1.247	.5005	1240	.00077	1.19	.967	182.4
2400	41.031	3943.2	1.254	.4903	1099	.00068	1.79	1.192	224.8
2000	16.858	3749.5	1.262	.4774	952	.00057	3.14	1.376	259.6
1600	5.868	3561.8	1.274	.4605	797	.00047	6.47	1.534	289.3
1200	1.595	3381.9	1.293	.4377	633	.00036	16.38	1.671	315.2
900	.461	3253.5	1.311	.4182	501	.00027	40.26	1.762	332.5
600	.088	3131.3	1.335	.3955	358	.00019	135.1	1.845	348.1
r = 4.00 (41.05 percent fuel by weight)									
3200	361.70	5252.2	1.218	0.5675	1459	0.00101	-------	-------	--------
2800	172.55	5027.2	1.223	.5572	1316	.00090	1.00	0.670	119.9
2400	74.676	4806.7	1.229	.5451	1167	.00078	1.30	1.023	183.2
2000	28.424	4591.6	1.237	.5298	1012	.00066	2.28	1.277	228.7
1600	9.056	4383.4	1.248	.5101	849	.00054	4.92	1.482	265.3
1200	2.214	4184.4	1.266	.4834	675	.00041	13.53	1.654	296.2
900	.582	4042.9	1.283	.4604	535	.00031	36.19	1.766	316.3
600	.098	3908.8	1.307	.4319	383	.00021	135.7	1.866	334.2

TABLE IV. - THEORETICAL PERFORMANCE AT ASSIGNED EXPANSION RATIOS FROM 1 TO 8 FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion.]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, ^{o}K	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(^{o}K)	Ratio of nozzle area to throat area, ϵ	Coefficient of thrust, C_F	Specific impulse, I, lb-sec/lb
r = 1.00 (14.83 percent fuel by weight)								
1.00	600.00	4007	2592.0	1.324	0.365	--------	--------	-------
1.02	588.24	3988	2584.9	1.325	.365	3.433	0.134	24.8
1.04	576.92	3969	2578.0	1.325	.365	2.478	.188	34.9
1.20	500.00	3832	2528.1	1.326	.363	1.292	.401	74.5
1.54	388.99	3602	2444.8	1.328	.362	1.028	.610	113.2
[a]1.85	324.15	3443	2387.4	1.330	.360	1.000	.719	133.4
2.31	259.33	3257	2320.6	1.332	.358	1.027	.828	153.7
4.00	150.00	2839	2171.7	1.338	.354	1.243	1.030	191.2
8.00	75.00	2380	2010.5	1.346	.348	1.772	1.211	224.9
r = 1.40 (19.60 percent fuel by weight)								
1.00	600.00	4464	3064.9	1.309	0.397	--------	--------	-------
1.02	588.24	4443	3056.6	1.310	.396	3.419	0.133	26.8
1.04	576.92	4423	3048.6	1.310	.396	2.469	.187	37.7
1.20	500.00	4275	2990.2	1.311	.395	1.288	.400	80.6
1.53	390.93	4032	2894.5	1.313	.393	1.028	.604	121.8
[a]1.84	325.77	3860	2827.0	1.315	.391	1.000	.714	143.9
2.30	260.62	3659	2748.4	1.317	.390	1.027	.823	165.9
4.00	150.00	3201	2571.1	1.322	.385	1.250	1.029	207.3
8.00	75.00	2700	2379.8	1.329	.378	1.790	1.212	244.2
r = 1.50 (20.71 percent fuel by weight)								
1.00	600.00	4479	3175.0	1.307	0.404	--------	--------	-------
1.02	588.24	4459	3166.6	1.307	.404	3.417	0.133	27.0
1.04	576.92	4438	3158.4	1.307	.404	2.467	.187	38.0
1.20	500.00	4291	3099.1	1.308	.403	1.287	.400	81.2
1.53	391.30	4050	3002.2	1.310	.400	1.028	.603	122.6
[a]1.84	326.07	3878	2933.6	1.312	.399	1.000	.713	144.9
2.30	260.87	3677	2853.7	1.314	.397	1.027	.823	167.2
4.00	150.00	3219	2672.9	1.319	.392	1.251	1.028	209.0
8.00	75.00	2719	2478.1	1.326	.386	1.794	1.212	246.2
r = 1.60 (21.79 percent fuel by weight)								
1.00	600.00	4396	3282.1	1.297	0.414	-------	--------	-------
1.02	588.24	4376	3273.8	1.297	.413	3.408	0.133	26.8
1.04	576.92	4357	3265.8	1.298	.413	2.461	.186	37.6
1.20	500.00	4216	3207.7	1.299	.412	1.285	.399	80.4
1.53	392.53	3987	3113.6	1.301	.410	1.029	.600	121.1
[a]1.83	327.10	3822	3046.2	1.302	.408	1.000	.710	143.3
2.29	261.69	3628	2967.4	1.304	.406	1.028	.820	165.5
4.00	150.00	3184	2788.1	1.310	.401	1.255	1.028	207.3
8.00	75.00	2699	2595.3	1.317	.394	1.805	1.212	244.5
r = 2.50 (30.33 percent fuel by weight)								
1.00	600.00	3898	4128.8	1.251	0.485	-------	-------	-------
1.02	588.24	3883	4121.3	1.251	.485	3.366	0.131	25.5
1.04	576.92	3868	4114.0	1.251	.485	2.432	.184	35.9
1.20	500.00	3758	4060.9	1.252	.483	1.273	.394	76.9
1.50	398.77	3590	3980.0	1.254	.481	1.031	.583	113.8
[a]1.81	332.31	3460	3917.4	1.255	.479	1.000	.695	135.6
2.26	265.85	3306	3843.9	1.257	.476	1.029	.807	157.5
4.00	150.00	2938	3670.1	1.262	.470	1.277	1.024	199.8
8.00	75.00	2542	3485.5	1.268	.461	1.866	1.213	236.6

[a] At throat.

TABLE IV. - Continued. THEORETICAL PERFORMANCE AT ASSIGNED EXPANSION RATIOS FROM 1 TO 8 FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion.]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, $^{\circ}K$	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)($^{\circ}K$)	Ratio of nozzle area to throat area, ε	Coefficient of thrust, C_F	Specific impulse, I, lb-sec/lb
r = 1.00 (14.83 percent fuel by weight)								
1.00	300.00	3910	2592.0	1.328	0.364	-------	--------	--------
1.02	294.11	3891	2585.0	1.328	.364	3.436	0.134	24.6
1.04	288.47	3872	2578.2	1.329	.364	2.480	.188	34.6
1.20	250.00	3738	2529.3	1.330	.362	1.293	.402	73.8
1.54	194.24	3510	2447.1	1.332	.361	1.028	.611	112.3
[a]1.85	161.86	3354	2390.9	1.334	.359	1.000	.720	132.3
2.32	129.50	3171	2325.4	1.336	.357	1.027	.829	152.3
4.00	75.00	2762	2180.0	1.342	.353	1.242	1.030	189.3
8.00	37.50	2311	2022.3	1.350	.347	1.767	1.211	222.6
r = 1.25 (17.87 percent fuel by weight)								
1.00	300.00	4238	2893.9	1.318	0.384	-------	--------	--------
1.02	294.11	4218	2886.1	1.318	.384	3.427	0.133	26.0
1.04	288.47	4198	2878.6	1.318	.384	2.474	.187	36.5
1.20	250.00	4055	2823.9	1.320	.383	1.290	.401	78.1
1.54	194.91	3818	2733.1	1.322	.380	1.028	.607	118.3
[a]1.85	162.42	3652	2670.1	1.323	.379	1.000	.717	139.6
2.31	129.94	3457	2596.6	1.326	.377	1.027	.826	160.8
4.00	75.00	3018	2432.0	1.331	.373	1.246	1.029	200.5
8.00	37.50	2537	2254.1	1.339	.366	1.780	1.211	235.9
r = 1.40 (19.60 percent fuel by weight)								
1.00	300.00	4332	3064.9	1.314	0.396	-------	--------	--------
1.02	294.11	4312	3056.8	1.314	.396	3.423	0.133	26.5
1.04	288.47	4292	3048.9	1.314	.395	2.471	.187	37.3
1.20	250.00	4148	2991.9	1.315	.394	1.289	.400	79.7
1.54	195.19	3908	2897.7	1.317	.392	1.028	.606	120.6
[a]1.84	162.66	3740	2831.9	1.319	.391	1.000	.715	142.4
2.31	130.13	3543	2755.1	1.321	.389	1.027	.825	164.2
4.00	75.00	3096	2582.5	1.326	.384	1.248	1.029	204.9
8.00	37.50	2607	2396.2	1.334	.377	1.785	1.212	241.2
r = 1.50 (20.71 percent fuel by weight)								
1.00	300.00	4346	3175.0	1.311	0.403	-------	--------	--------
1.02	294.11	4326	3166.8	1.311	.403	3.421	0.133	26.7
1.04	288.47	4306	3158.8	1.311	.403	2.470	.187	37.6
1.20	250.00	4162	3100.8	1.312	.402	1.288	.400	80.3
1.54	195.38	3925	3005.5	1.315	.400	1.028	.605	121.4
[a]1.84	162.82	3757	2938.6	1.316	.398	1.000	.714	143.4
2.30	130.25	3560	2860.5	1.318	.396	1.027	.824	165.4
4.00	75.00	3113	2684.6	1.323	.391	1.249	1.029	206.6
8.00	37.50	2625	2494.9	1.331	.385	1.788	1.212	243.3
r = 1.60 (21.79 percent by weight)								
1.00	300.00	4267	3282.1	1.302	0.412	--------	--------	--------
1.02	294.11	4247	3274.0	1.302	.412	3.412	0.133	26.5
1.04	288.47	4228	3266.1	1.302	.412	2.464	.187	37.2
1.20	250.00	4090	3209.3	1.303	.411	1.286	.399	79.6
1.53	195.99	3864	3116.8	1.305	.409	1.029	.602	119.9
[a]1.84	163.32	3702	3050.9	1.307	.407	1.000	.711	141.8
2.30	130.65	3513	2974.0	1.309	.405	1.027	.821	163.7
4.00	75.00	3079	2799.4	1.314	.400	1.253	1.028	204.9
8.00	37.50	2605	2611.5	1.321	.393	1.799	1.212	241.5

[a]At throat.

TABLE IV. - Concluded. THEORETICAL PERFORMANCE AT ASSIGNED EXPANSION RATIOS FROM 1 TO 8 FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion.]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute.

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Enthalpy, h, cal/g	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(°K)	Ratio of nozzle area to throat area, ε	Coefficient of thrust, C_F	Specific impulse, I, lb-sec/lb
r = 1.75 (23.35 percent fuel by weight)								
1.00	300.00	4163	3437.3	1.290	0.426	--------	--------	-------
1.02	294.11	4144	3429.4	1.290	.426	3.402	0.132	26.2
1.04	288.47	4126	3421.7	1.290	.426	2.456	.186	36.8
1.20	250.00	3995	3366.1	1.291	.424	1.283	.398	78.7
1.52	196.76	3785	3276.9	1.293	.422	1.029	.597	118.1
[a]1.83	163.96	3631	3212.2	1.295	.420	1.000	.708	140.0
2.29	131.17	3451	3136.6	1.297	.418	1.028	.818	161.8
4.00	75.00	3034	2963.2	1.302	.413	1.259	1.027	203.1
8.00	37.50	2580	2777.3	1.309	.406	1.814	1.212	239.6
r = 2.00 (25.83 percent fuel by weight)								
1.00	300.00	4067	3682.7	1.276	0.447	--------	--------	-------
1.02	294.11	4050	3674.9	1.276	.447	3.389	0.132	26.0
1.04	288.47	4033	3667.3	1.276	.447	2.448	.185	36.6
1.20	250.00	3910	3612.4	1.277	.445	1.280	.397	78.2
1.52	197.68	3715	3525.8	1.279	.443	1.030	.592	116.8
[a]1.82	164.74	3569	3461.6	1.281	.441	1.000	.703	138.7
2.28	131.79	3399	3386.5	1.283	.439	1.028	.814	160.5
4.00	75.00	2999	3212.3	1.288	.433	1.265	1.026	202.3
8.00	37.50	2565	3026.1	1.294	.425	1.832	1.212	239.0
r = 2.50 (30.33 percent fuel by weight)								
1.00	300.00	3813	4128.8	1.254	0.484	--------	-------	-------
1.02	294.11	3798	4121.4	1.254	.484	3.369	0.131	25.4
1.04	288.47	3783	4114.2	1.254	.484	2.434	.184	35.7
1.20	250.00	3675	4061.9	1.255	.482	1.274	.394	76.3
1.51	199.17	3508	3981.8	1.257	.480	1.030	.585	113.1
[a]1.81	165.98	3380	3920.2	1.258	.478	1.000	.696	134.7
2.26	132.78	3228	3847.9	1.260	.475	1.029	.808	156.3
4.00	75.00	2866	3677.4	1.265	.468	1.276	1.024	198.2
8.00	37.50	2476	3496.0	1.271	.460	1.862	1.213	234.7
r = 3.00 (34.31 percent fuel by weight)								
1.00	300.00	3552	4523.9	1.238	0.516	--------	--------	--------
1.02	294.11	3539	4517.0	1.238	.515	3.354	0.130	24.6
1.04	288.47	3526	4510.2	1.238	.515	2.423	.183	34.6
1.20	250.00	3430	4460.8	1.239	.513	1.270	.393	74.1
1.50	200.26	3286	4387.0	1.241	.511	1.031	.579	109.2
[a]1.80	166.89	3271	4328.6	1.242	.508	1.000	.691	130.4
2.25	133.51	3036	4259.9	1.244	.506	1.029	.803	151.6
4.00	75.00	2709	4095.8	1.248	.498	1.284	1.023	193.0
8.00	37.50	2357	3921.9	1.254	.489	1.884	1.213	228.9
r = 4.00 (41.05 percent fuel by weight)								
1.00	300.00	3095	5192.5	1.219	0.565	--------	--------	--------
1.02	294.11	3084	5186.3	1.219	.565	3.336	0.130	23.2
1.04	288.47	3073	5180.2	1.219	.564	2.410	.182	32.7
1.20	250.00	2995	5136.2	1.220	.562	1.265	.391	70.0
1.49	201.60	2880	5072.1	1.222	.559	1.032	.572	102.4
[a]1.79	168.00	2786	5019.7	1.223	.557	1.000	.685	122.6
2.23	134.40	2675	4957.8	1.224	.554	1.030	.798	142.9
4.00	75.00	2402	4807.7	1.229	.545	1.294	1.022	183.0
8.00	37.50	2109	4649.3	1.234	.534	1.912	1.214	217.4

[a]At throat.

TABLE V. - THEORETICAL PERFORMANCE AT ASSIGNED EXPANSION RATIOS FROM 10 TO 1500 FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion.]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, $^{\circ}K$	Temperature exponent, n_T, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/g ($^{\circ}K$)	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)($^{\circ}K$)	Ratio of nozzle area to throat area, ϵ	Area-ratio exponent, n_{ϵ}, $\left(\frac{\Delta \log \epsilon}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Coefficient of thrust, C_F	Specific-impulse exponent, n_I, $\left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, lb-sec/lb
r = 1.00 (14.83 percent fuel by weight)											
10	60.00	2247	0.0431	1964.4	1.349	0.346	2.01	0.0045	1.259	0.0150	233.7
15	40.00	2022	.0446	1887.1	1.354	.341	2.56	.0058	1.334	.0152	247.6
20	30.00	1875	.0457	1837.1	1.359	.338	3.06	.0067	1.380	.0154	256.3
30	20.00	1683	.0473	1772.7	1.365	.334	3.96	.0080	1.438	.0157	267.0
40	15.00	1558	.0485	1731.0	1.370	.331	4.77	.0090	1.474	.0159	273.7
60	10.00	1395	.0501	1677.6	1.377	.326	6.21	.0104	1.519	.0161	282.1
80	7.50	1289	.0513	1643.1	1.383	.323	7.51	.0114	1.547	.0163	287.3
100	6.00	1211	.0523	1618.2	1.387	.320	8.71	.0122	1.568	.0164	291.1
150	4.00	1081	0.0539	1576.7	1.394	0.316	11.42	0.0137	1.601	0.0167	297.2
200	3.00	996	.0551	1550.1	1.399	.313	13.85	.0147	1.622	.0168	301.1
300	2.00	887	.0567	1516.0	1.406	.309	18.20	.0160	1.648	.0170	306.0
400	1.50	816	.0577	1494.1	1.410	.307	22.10	.0169	1.665	.0172	309.1
600	1.00	725	.0591	1466.2	1.416	.304	29.08	.0182	1.686	.0174	313.0
800	.75	666	.0601	1448.4	1.419	.303	35.35	.0190	1.699	.0175	315.4
1000	.60	623	.0607	1435.5	1.421	.302	41.14	.0196	1.708	.0176	317.2
1500	.40	553	.0619	1414.3	1.424	.300	54.21	.0206	1.724	.0177	320.1
r = 1.40 (19.60 percent fuel by weight)											
10	60.00	2554	0.0513	2324.9	1.332	0.376	2.04	0.0048	1.259	0.0176	253.8
15	40.00	2307	.0529	2232.6	1.337	.372	2.60	.0061	1.335	.0179	269.1
20	30.00	2145	.0540	2172.6	1.341	.369	3.12	.0070	1.383	.0181	278.7
30	20.00	1934	.0557	2095.1	1.347	.364	4.04	.0084	1.442	.0184	290.5
40	15.00	1795	.0569	2044.8	1.352	.360	4.88	.0094	1.478	.0186	297.9
60	10.00	1614	.0587	1980.1	1.359	.355	6.38	.0109	1.525	.0189	307.2
80	7.50	1496	.0600	1938.2	1.364	.351	7.73	.0120	1.554	.0191	313.1
100	6.00	1409	.0610	1907.8	1.368	.348	8.98	.0129	1.575	.0192	317.3
150	4.00	1262	0.0628	1857.1	1.376	0.343	11.82	0.0145	1.609	0.0195	324.2
200	3.00	1166	.0641	1824.4	1.382	.339	14.36	.0156	1.630	.0196	328.5
300	2.00	1042	.0659	1782.5	1.390	.334	18.93	.0171	1.658	.0199	334.0
400	1.50	961	.0671	1755.5	1.395	.331	23.03	.0182	1.675	.0200	337.5
600	1.00	856	.0687	1721.1	1.402	.327	30.38	.0196	1.697	.0202	342.0
800	.75	788	.0698	1698.9	1.406	.324	36.99	.0205	1.711	.0204	344.8
1000	.60	738	.0706	1683.0	1.410	.323	43.09	.0212	1.721	.0205	346.8
1500	.40	656	.0719	1656.5	1.414	.320	56.89	.0224	1.737	.0206	350.1
r = 1.50 (20.71 percent fuel by weight)											
10	60.00	2573	0.0516	2422.2	1.329	0.383	2.04	0.0048	1.259	0.0177	255.9
15	40.00	2326	.0532	2328.0	1.334	.379	2.61	.0061	1.336	.0180	271.5
20	30.00	2164	.0544	2266.8	1.338	.376	3.13	.0070	1.383	.0182	281.1
30	20.00	1952	.0560	2187.7	1.344	.371	4.06	.0084	1.442	.0185	293.1
40	15.00	1813	.0573	2136.3	1.348	.367	4.90	.0094	1.479	.0187	300.6
60	10.00	1631	.0590	2070.2	1.355	.362	6.41	.0109	1.526	.0189	310.1
80	7.50	1512	.0603	2027.3	1.361	.358	7.77	.0120	1.555	.0191	316.0
100	6.00	1425	.0613	1996.2	1.365	.355	9.04	.0129	1.576	.0193	320.3
150	4.00	1278	0.0632	1944.3	1.373	0.349	11.89	0.0145	1.610	0.0195	327.2
200	3.00	1181	.0645	1910.8	1.378	.346	14.46	.0156	1.632	.0197	331.7
300	2.00	1056	.0662	1867.8	1.386	.340	19.07	.0172	1.659	.0199	337.3
400	1.50	974	.0675	1840.1	1.392	.337	23.21	.0182	1.677	.0201	340.8
600	1.00	868	.0691	1804.7	1.399	.333	30.64	.0197	1.699	.0203	345.3
800	.75	800	.0702	1782.0	1.403	.330	37.32	.0206	1.713	.0204	348.2
1000	.60	750	.0710	1765.6	1.407	.328	43.49	.0213	1.723	.0205	350.2
1500	.40	667	.0724	1738.4	1.412	.325	57.44	.0225	1.740	.0207	353.6
r = 1.60 (21.79 percent fuel by weight)											
10	60.00	2557	0.0519	2539.7	1.319	0.392	2.06	0.0051	1.260	0.0175	254.2
15	40.00	2317	.0535	2446.1	1.324	.387	2.63	.0065	1.337	.0178	269.7
20	30.00	2159	.0548	2385.1	1.328	.384	3.16	.0075	1.385	.0180	279.4
30	20.00	1952	.0566	2306.2	1.334	.379	4.11	.0089	1.444	.0183	291.4
40	15.00	1816	.0579	2254.9	1.338	.375	4.96	.0100	1.482	.0185	299.0
60	10.00	1638	.0597	2188.6	1.345	.370	6.51	.0116	1.529	.0188	308.5
80	7.50	1521	.0611	2145.5	1.350	.366	7.91	.0128	1.559	.0190	314.5
100	6.00	1435	.0622	2114.3	1.354	.362	9.20	.0137	1.580	.0192	318.8
150	4.00	1290	0.0642	2062.0	1.362	0.357	12.13	0.0154	1.615	0.0194	325.8
200	3.00	1194	.0656	2028.1	1.367	.353	14.78	.0166	1.637	.0196	330.3
300	2.00	1070	.0675	1984.7	1.375	.348	19.53	.0183	1.665	.0199	336.0
400	1.50	989	.0688	1956.6	1.380	.344	23.81	.0195	1.683	.0201	339.6
600	1.00	884	.0707	1920.7	1.387	.340	31.49	.0211	1.706	.0203	344.2
800	.75	815	.0719	1897.5	1.392	.337	38.41	.0222	1.720	.0204	347.1
1000	.60	766	.0728	1880.8	1.395	.335	44.81	.0229	1.731	.0206	349.2
1500	.40	682	.0744	1853.0	1.400	.331	59.30	.0243	1.748	.0207	352.6
r = 2.50 (30.33 percent fuel by weight)											
10	60.00	2424	0.0386	3431.6	1.270	0.458	2.14	0.0039	1.263	0.0120	246.3
15	40.00	2223	.0399	3339.9	1.274	.453	2.76	.0050	1.343	.0123	262.0
20	30.00	2089	.0408	3279.5	1.277	.449	3.34	.0057	1.394	.0124	271.8
30	20.00	1912	.0422	3200.6	1.282	.443	4.38	.0068	1.457	.0127	284.2
40	15.00	1795	.0431	3148.7	1.285	.439	5.34	.0076	1.497	.0129	292.0
60	10.00	1639	.0446	3080.9	1.291	.432	7.07	.0088	1.548	.0131	302.0
80	7.50	1536	.0456	3036.5	1.295	.428	8.65	.0097	1.580	.0133	308.3
100	6.00	1459	.0464	3004.0	1.298	.424	10.13	.0104	1.604	.0134	312.9
150	4.00	1329	0.0479	2949.0	1.304	0.417	13.51	0.0117	1.642	0.0136	320.4
200	3.00	1242	.0490	2913.0	1.309	.413	16.58	.0126	1.667	.0138	325.3
300	2.00	1128	.0506	2866.2	1.315	.406	22.16	.0140	1.699	.0140	331.5
400	1.50	1052	.0516	2835.7	1.320	.402	27.25	.0149	1.719	.0141	335.4
600	1.00	953	.0531	2796.2	1.326	.396	36.46	.0162	1.746	.0143	340.5
800	.75	888	.0542	2770.4	1.330	.392	44.85	.0171	1.762	.0144	343.8
1000	.60	840	.0550	2751.7	1.334	.389	52.66	.0178	1.774	.0145	346.2
1500	.40	758	.0565	2720.1	1.340	.384	70.52	.0191	1.795	.0147	350.1

TABLE V. - Continued. THEORETICAL PERFORMANCE AT ASSIGNED EXPANSION RATIOS FROM 10 TO 1500 FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Frozen composition during isentropic expansion.]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/g (°K)	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(°K)	Ratio of nozzle area to throat area, ϵ	Area-ratio exponent, n_ϵ, $\left(\frac{\Delta \log \epsilon}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Coefficient of thrust, C_F	Specific-impulse exponent, n_I, $\left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, lb-sec/lb
r = 1.00 (14.83 percent fuel by weight)											
10	30.00	2181	0.0431	1977.3	1.353	0.344	2.01	0.0045	1.258	0.0150	231.3
15	20.00	1960	.0446	1901.9	1.359	.340	2.55	.0058	1.333	.0152	245.0
20	15.00	1816	.0457	1853.0	1.364	.337	3.05	.0067	1.380	.0154	253.6
30	10.00	1629	.0473	1790.3	1.370	.333	3.94	.0080	1.437	.0157	264.1
40	7.50	1506	.0485	1749.8	1.376	.329	4.74	.0090	1.473	.0159	270.7
60	5.00	1347	.0501	1697.8	1.383	.325	6.17	.0104	1.518	.0161	278.9
80	3.75	1244	.0513	1664.3	1.388	.321	7.45	.0114	1.546	.0163	284.1
100	3.00	1168	.0523	1640.1	1.392	.319	8.64	.0122	1.566	.0164	287.8
150	2.00	1041	0.0539	1599.9	1.400	0.315	11.31	0.0137	1.599	0.0167	293.8
200	1.50	959	.0551	1574.1	1.405	.312	13.71	.0147	1.619	.0168	297.6
300	1.00	853	.0567	1541.1	1.411	.309	18.00	.0160	1.645	.0170	302.4
400	.75	784	.0577	1519.9	1.415	.306	21.85	.0169	1.662	.0172	305.4
600	.50	696	.0591	1493.0	1.420	.304	28.72	.0182	1.683	.0174	309.2
800	.37	639	.0601	1475.8	1.423	.302	34.89	.0190	1.696	.0175	311.6
1000	.30	598	.0607	1463.4	1.425	.301	40.58	.0196	1.705	.0176	313.4
1500	.20	529	.0619	1442.9	1.427	.300	53.44	.0206	1.720	.0177	316.2
r = 1.25 (17.87 percent fuel by weight)											
10	30.00	2397		2203.1	1.342	0.364	2.02		1.259		245.2
15	20.00	2161		2117.6	1.347	.360	2.58		1.334		259.9
20	15.00	2006		2062.1	1.351	.356	3.09		1.381		269.0
30	10.00	1804		1990.7	1.358	.352	3.99		1.439		280.3
40	7.50	1671		1944.4	1.363	.348	4.81		1.476		287.4
60	5.00	1499		1884.9	1.370	.343	6.28		1.521		296.3
80	3.75	1387		1846.5	1.376	.339	7.60		1.550		301.9
100	3.00	1304		1818.7	1.380	.336	8.82		1.571		305.9
150	2.00	1166		1772.3	1.388	0.331	11.58		1.604		312.4
200	1.50	1075		1742.5	1.393	.328	14.06		1.625		316.5
300	1.00	958		1704.4	1.401	.324	18.49		1.652		321.7
400	.75	882		1679.9	1.406	.321	22.46		1.669		325.0
600	.50	784		1648.6	1.412	.317	29.57		1.690		329.2
800	.37	721		1628.6	1.416	.315	35.96		1.704		331.8
1000	.30	675		1614.2	1.418	.314	41.86		1.713		333.7
1500	.20	599		1590.3	1.422	.312	55.18		1.729		336.8
r = 1.40 (19.60 percent fuel by weight)											
10	30.00	2465	0.0513	2342.7	1.337	0.375	2.03	0.0048	1.259	0.0176	250.7
15	20.00	2224	.0529	2253.0	1.342	.371	2.59	.0061	1.335	.0179	265.8
20	15.00	2066	.0540	2194.7	1.346	.368	3.10	.0070	1.382	.0181	275.2
30	10.00	1861	.0557	2119.5	1.352	.363	4.02	.0084	1.441	.0184	286.8
40	7.50	1726	.0569	2070.8	1.357	.359	4.85	.0094	1.477	.0186	294.1
60	5.00	1550	.0587	2008.1	1.364	.354	6.33	.0109	1.523	.0189	303.2
80	3.75	1435	.0600	1967.6	1.370	.350	7.67	.0120	1.552	.0191	309.0
100	3.00	1350	.0610	1938.2	1.374	.347	8.90	.0129	1.573	.0192	313.1
150	2.00	1208	0.0628	1889.3	1.382	0.342	11.70	0.0145	1.606	0.0195	319.8
200	1.50	1115	.0641	1857.7	1.388	.338	14.21	.0156	1.628	.0196	324.1
300	1.00	995	.0659	1817.3	1.395	.333	18.71	.0171	1.655	.0199	329.5
400	.75	917	.0671	1791.4	1.401	.330	22.75	.0182	1.672	.0200	332.9
600	.50	816	.0687	1758.2	1.407	.326	29.97	.0196	1.694	.0202	337.2
800	.37	751	.0698	1736.9	1.411	.324	36.47	.0205	1.707	.0204	339.9
1000	.30	703	.0706	1721.6	1.414	.322	42.46	.0212	1.717	.0205	341.9
1500	.20	624	.0719	1696.2	1.419	.320	56.01	.0224	1.733	.0206	345.1
r = 1.50 (20.71 percent fuel by weight)											
10	30.00	2483	0.0516	2440.4	1.333	0.382	2.03	0.0048	1.259	0.0177	252.8
15	20.00	2242	.0532	2348.9	1.339	.378	2.60	.0061	1.335	.0180	268.1
20	15.00	2084	.0544	2289.4	1.343	.375	3.11	.0070	1.383	.0182	277.6
30	10.00	1878	.0560	2212.7	1.349	.370	4.03	.0084	1.441	.0185	289.4
40	7.50	1742	.0573	2162.9	1.354	.366	4.87	.0094	1.478	.0187	296.8
60	5.00	1566	.0590	2098.8	1.361	.361	6.36	.0109	1.524	.0189	306.0
80	3.75	1450	.0603	2057.3	1.366	.357	7.71	.0120	1.553	.0191	311.9
100	3.00	1366	.0613	2027.3	1.371	.354	8.95	.0129	1.574	.0193	316.0
150	2.00	1223	0.0632	1977.2	1.379	0.348	11.77	0.0145	1.608	0.0195	322.8
200	1.50	1129	.0645	1944.8	1.384	.344	14.31	.0156	1.629	.0197	327.2
300	1.00	1008	.0662	1903.4	1.392	.340	18.84	.0172	1.657	.0199	332.6
400	.75	930	.0675	1876.8	1.397	.336	22.92	.0182	1.674	.0201	336.1
600	.50	828	.0691	1842.7	1.404	.332	30.22	.0197	1.696	.0203	340.5
800	.37	762	.0702	1820.9	1.408	.330	36.79	.0206	1.710	.0204	343.3
1000	.30	714	.0710	1805.2	1.411	.328	42.85	.0213	1.719	.0205	345.2
1500	.20	634	.0724	1779.1	1.416	.325	56.55	.0225	1.736	.0207	348.5
r = 1.60 (21.79 percent fuel by weight)											
10	30.00	2467	0.0519	2557.5	1.324	0.390	2.05	0.0051	1.260	0.0175	251.1
15	20.00	2233	.0535	2466.5	1.329	.386	2.62	.0065	1.336	.0178	266.4
20	15.00	2079	.0548	2407.2	1.333	.382	3.14	.0075	1.384	.0180	275.9
30	10.00	1877	.0566	2330.7	1.339	.377	4.08	.0089	1.443	.0183	287.7
40	7.50	1745	.0579	2280.9	1.344	.374	4.93	.0100	1.481	.0185	295.2
60	5.00	1571	.0597	2216.7	1.351	.368	6.46	.0116	1.527	.0188	304.5
80	3.75	1458	.0611	2175.1	1.356	.364	7.84	.0128	1.557	.0190	310.4
100	3.00	1374	.0622	2144.9	1.360	.361	9.11	.0137	1.578	.0192	314.6
150	2.00	1233	0.0642	2094.4	1.368	0.355	12.00	0.0154	1.613	0.0194	321.5
200	1.50	1141	.0656	2061.8	1.373	.351	14.61	.0166	1.635	.0196	325.9
300	1.00	1021	.0675	2020.0	1.381	.346	19.28	.0183	1.662	.0199	331.4
400	.75	943	.0688	1993.0	1.386	.343	23.49	.0195	1.680	.0201	334.9
600	.50	842	.0707	1958.4	1.393	.339	31.03	.0211	1.702	.0203	339.4
800	.37	776	.0719	1936.2	1.397	.336	37.82	.0222	1.717	.0204	342.2
1000	.30	728	.0728	1920.2	1.401	.334	44.10	.0229	1.727	.0206	344.2
1500	.20	648	.0744	1893.6	1.405	.331	58.31	.0243	1.744	.0207	347.6

TABLE V. - Concluded. THEORETICAL PERFORMANCE AT ASSIGNED EXPANSION RATIOS FROM 10 TO 1500 FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion.]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute.

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\Delta \log T}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/(g)(°K)	Isentropic exponent, γ	Specific heat at constant pressure, c_p, cal/(g)(°K)	Ratio of nozzle area to throat area, ϵ	Area-ratio exponent, n_ϵ, $\left(\frac{\Delta \log \epsilon}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Coefficient of thrust, C_F	Specific-impulse exponent, n_I, $\left(\frac{\Delta \log I}{\Delta \log P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, lb-sec/lb
r = 1.75 (23.35 percent fuel by weight)											
10	30.00	2447		2723.7	1.312	0.403	2.07		1.260		249.2
15	20.00	2221		2633.1	1.317	.398	2.65		1.338		264.5
20	15.00	2072		2574.0	1.320	.395	3.18		1.386		274.1
30	10.00	1876		2497.4	1.326	.389	4.15		1.446		286.0
40	7.50	1748		2447.5	1.331	.385	5.02		1.484		293.5
60	5.00	1579		2383.0	1.337	.380	6.59		1.532		302.9
80	3.75	1468		2341.1	1.342	.376	8.01		1.562		308.8
100	3.00	1386		2310.6	1.346	.372	9.33		1.583		313.1
150	2.00	1248		2259.5	1.354	0.367	12.32		1.619		320.1
200	1.50	1157		2226.4	1.359	.363	15.02		1.642		324.6
300	1.00	1039		2183.8	1.366	.357	19.88		1.670		330.3
400	.75	962		2156.2	1.371	.354	24.27		1.688		333.9
600	.50	861		2120.9	1.378	.349	32.15		1.712		338.4
800	.37	795		2098.1	1.383	.346	39.26		1.726		341.4
1000	.30	748		2081.6	1.386	.344	45.85		1.737		343.5
1500	.20	667		2054.2	1.391	.341	60.79		1.754		346.9
r = 2.00 (25.83 percent fuel by weight)											
10	30.00	2438		2972.2	1.297	0.423	2.09		1.261		248.6
15	20.00	2221		2880.9	1.301	.418	2.69		1.340		264.1
20	15.00	2077		2821.1	1.305	.414	3.24		1.389		273.8
30	10.00	1888		2743.4	1.310	.408	4.23		1.450		285.9
40	7.50	1763		2692.7	1.314	.404	5.13		1.488		293.5
60	5.00	1599		2626.8	1.320	.398	6.75		1.537		303.1
80	3.75	1491		2583.8	1.325	.394	8.23		1.568		309.2
100	3.00	1411		2552.5	1.329	.391	9.60		1.590		313.6
150	2.00	1275		2499.9	1.336	0.385	12.72		1.627		320.8
200	1.50	1186		2465.7	1.341	.380	15.55		1.650		325.4
300	1.00	1069		2421.5	1.348	.375	20.65		1.680		331.3
400	.75	992		2392.9	1.353	.371	25.27		1.699		335.0
600	.50	892		2356.0	1.360	.365	33.59		1.723		339.8
800	.37	826		2332.1	1.364	.362	41.12		1.738		342.8
1000	.30	778		2314.8	1.368	.360	48.11		1.750		345.0
1500	.20	697		2285.9	1.374	.355	64.00		1.768		348.6
r = 2.50 (30.33 percent fuel by weight)											
10	30.00	2360	0.0386	3443.1	1.273	0.457	2.13	0.0039	1.262	0.0120	244.3
15	20.00	2163	.0399	3353.2	1.277	.452	2.75	.0050	1.343	.0123	259.8
20	15.00	2031	.0408	3294.1	1.281	.448	3.32	.0057	1.393	.0124	269.5
30	10.00	1857	.0422	3216.8	1.286	.442	4.36	.0068	1.456	.0127	281.7
40	7.50	1742	.0431	3166.0	1.289	.437	5.31	.0076	1.496	.0129	289.4
60	5.00	1589	.0446	3099.8	1.295	.431	7.03	.0088	1.546	.0131	299.2
80	3.75	1488	.0456	3056.4	1.299	.426	8.59	.0097	1.579	.0133	305.5
100	3.00	1413	.0464	3024.6	1.302	.423	10.06	.0104	1.602	.0134	310.0
150	2.00	1285	0.0479	2971.0	1.309	0.416	13.40	0.0117	1.640	0.0136	317.4
200	1.50	1201	.0490	2935.9	1.313	.411	16.44	.0126	1.665	.0138	322.2
300	1.00	1089	.0506	2890.5	1.320	.405	21.95	.0140	1.696	.0140	328.3
400	.75	1015	.0516	2860.8	1.324	.401	26.97	.0149	1.717	.0141	332.2
600	.50	919	.0531	2822.4	1.331	.395	36.06	.0162	1.742	.0143	337.2
800	.37	855	.0542	2797.3	1.335	.391	44.32	.0171	1.759	.0144	340.4
1000	.30	808	.0550	2779.1	1.338	.388	52.02	.0178	1.771	.0145	342.7
1500	.20	729	.0565	2748.6	1.344	.383	69.60	.0191	1.791	.0147	346.6
r = 3.00 (34.31 percent fuel by weight)											
10	30.00	2252		3870.9	1.256	0.486	2.16		1.264		238.4
15	20.00	2072		3784.0	1.260	.480	2.80		1.345		253.7
20	15.00	1952		3726.7	1.263	.476	3.39		1.396		263.4
30	10.00	1793		3651.4	1.268	.469	4.46		1.461		275.5
40	7.50	1686		3601.8	1.271	.465	5.45		1.502		283.3
60	5.00	1546		3536.8	1.277	.458	7.24		1.554		293.1
80	3.75	1452		3494.1	1.281	.453	8.87		1.587		299.4
100	3.00	1382		3462.7	1.284	.449	10.40		1.611		303.9
150	2.00	1263		3409.6	1.290	0.442	13.91		1.651		311.4
200	1.50	1183		3374.7	1.294	.437	17.12		1.676		316.2
300	1.00	1079		3329.2	1.300	.430	22.95		1.709		322.4
400	.75	1009		3299.5	1.304	.426	28.28		1.730		326.4
600	.50	917		3260.8	1.310	.419	37.97		1.757		331.5
800	.37	857		3235.5	1.314	.415	46.82		1.775		334.8
1000	.30	812		3217.0	1.317	.412	55.08		1.788		337.2
1500	.20	736		3185.9	1.323	.406	74.01		1.809		341.2
r = 4.00 (41.05 percent fuel by weight)											
10	30.00	2021		4602.6	1.236	0.531	2.20		1.265		226.6
15	20.00	1869		4522.6	1.240	.524	2.86		1.348		241.4
20	15.00	1767		4469.6	1.243	.519	3.47		1.400		250.8
30	10.00	1632		4399.7	1.247	.512	4.59		1.467		262.6
40	7.50	1541		4353.4	1.250	.507	5.62		1.509		270.2
60	5.00	1420		4292.5	1.255	.499	7.50		1.563		279.8
80	3.75	1339		4252.3	1.259	.493	9.23		1.597		286.0
100	3.00	1279		4222.6	1.262	.489	10.85		1.622		290.5
150	2.00	1175		4172.2	1.267	0.482	14.57		1.664		298.0
200	1.50	1105		4139.0	1.271	.476	17.99		1.691		302.8
300	1.00	1013		4095.4	1.276	.469	24.24		1.725		309.0
400	.75	952		4066.8	1.279	.465	29.98		1.748		313.0
600	.50	870		4029.3	1.285	.458	40.46		1.776		318.1
800	.37	816		4004.7	1.288	.453	50.08		1.795		321.5
1000	.30	777		3986.7	1.291	.450	59.09		1.809		323.9
1500	.20	708		3956.2	1.297	.443	79.83		1.831		328.0

TABLE VI. - THEORETICAL PERFORMANCE FOR EXPANSION TO 1 ATMOSPHERE FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Frozen composition during isentropic expansion.]

Equivalence ratio, r, $\frac{4(C)+(H)}{2(O)+(F)}$	Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Combustion temperature, T_c, ^{o}K	Exit temperature, T_e, ^{o}K	Characteristic velocity, c*, ft/sec	Coefficient of thrust, C_F	Nozzle area ratio, ϵ	Specific impulse, I, lb-sec/lb
Chamber pressure, 600 lb/sq in. abs (expansion ratio, 40.83)								
1.00	14.83	5.743	4007	1549	5974	1.476	4.83	274.2
1.25	17.87	4.595	4359	1726	6338	1.480	4.91	291.5
1.40	19.60	4.102	4464	1786	6484	1.481	4.94	298.4
1.50	20.71	3.829	4479	1803	6539	1.482	4.96	301.1
1.60	21.79	3.589	4396	1807	6491	1.484	5.03	299.5
1.75	23.35	3.282	4269	1803	6422	1.488	5.12	297.0
2.00	25.83	2.872	4168	1816	6402	1.492	5.23	297.0
2.50	30.33	2.297	3898	1787	6277	1.500	5.41	292.6
3.00	34.31	1.914	3618	1721	6111	1.505	5.55	285.9
4.00	41.05	1.436	3125	1555	5783	1.512	5.72	271.8
Chamber pressure, 300 lb/sq in. abs (expansion ratio, 20.41)								
1.00	14.83	5.743	3910	1806	5913	1.383	3.09	254.1
1.25	17.87	4.595	4238	1995	6266	1.384	3.13	269.6
1.40	19.60	4.102	4332	2056	6406	1.385	3.14	275.8
1.50	20.71	3.829	4346	2073	6460	1.386	3.15	278.2
1.60	21.79	3.589	4267	2068	6414	1.387	3.18	276.5
1.75	23.35	3.282	4163	2061	6362	1.389	3.23	274.7
2.00	25.83	2.872	4067	2067	6344	1.392	3.28	274.5
2.50	30.33	2.297	3813	2022	6226	1.396	3.37	270.2
3.00	34.31	1.914	3552	1944	6070	1.400	3.44	264.0
4.00	41.05	1.436	3095	1760	5762	1.404	3.52	251.4

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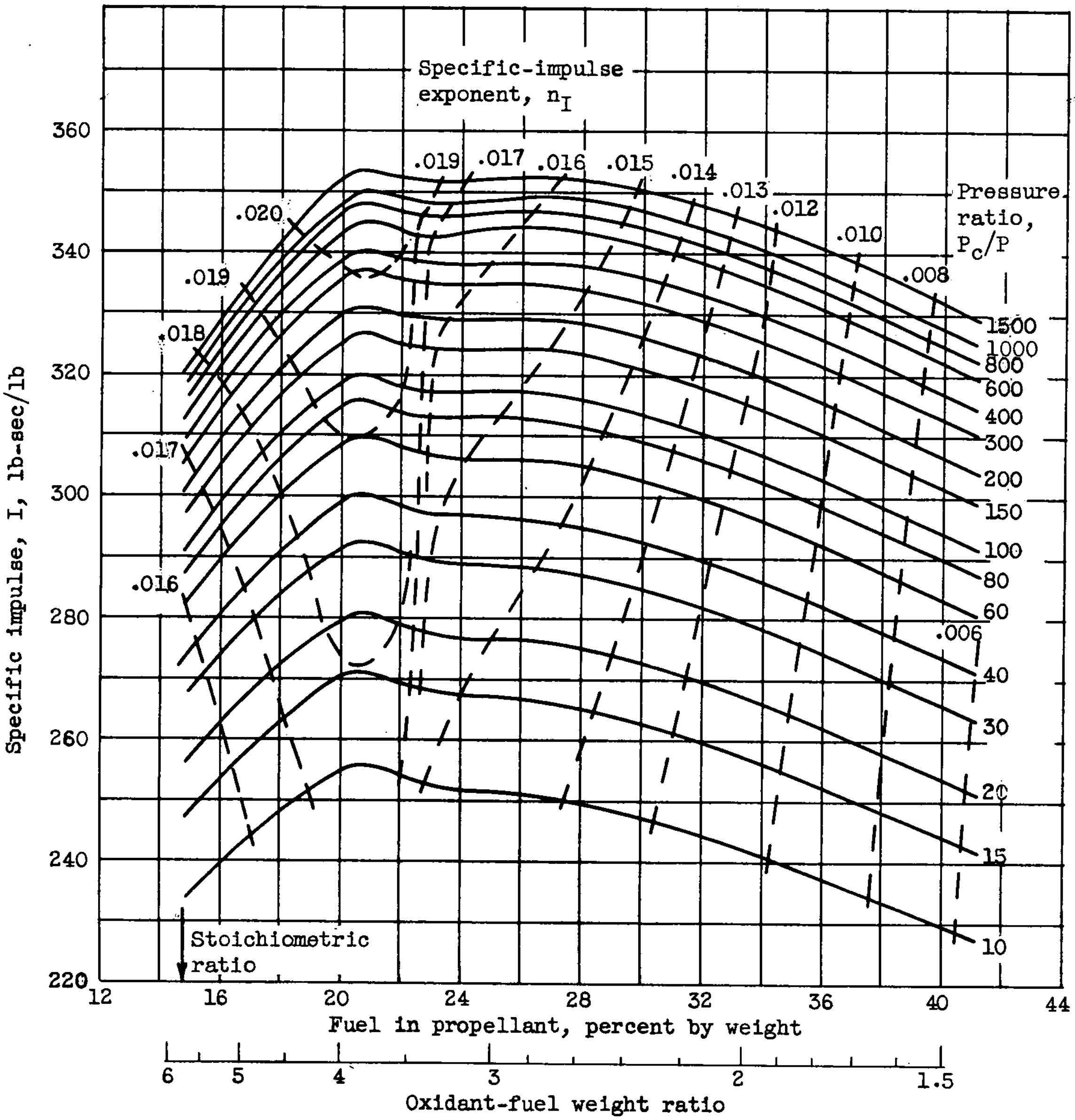
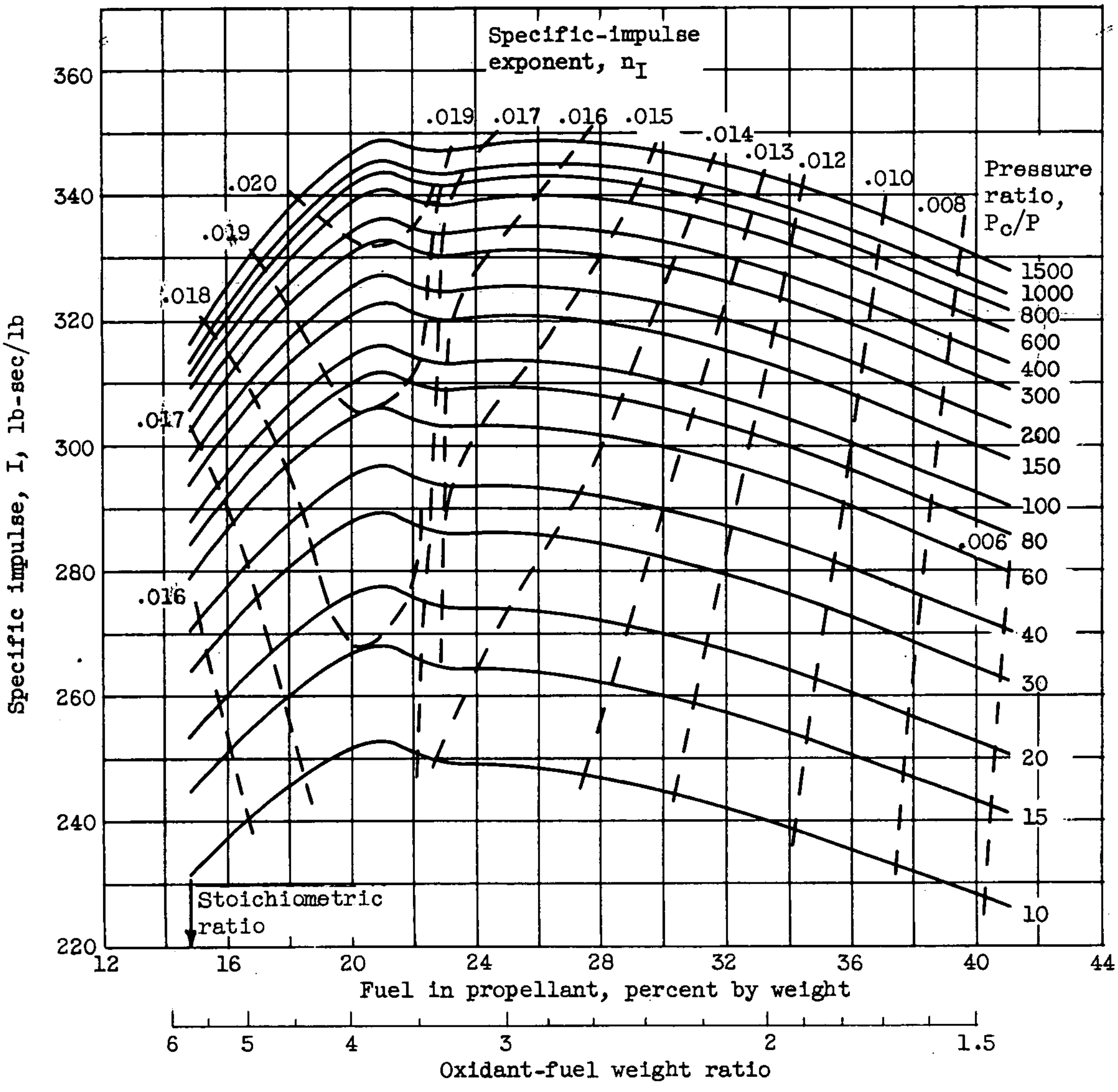


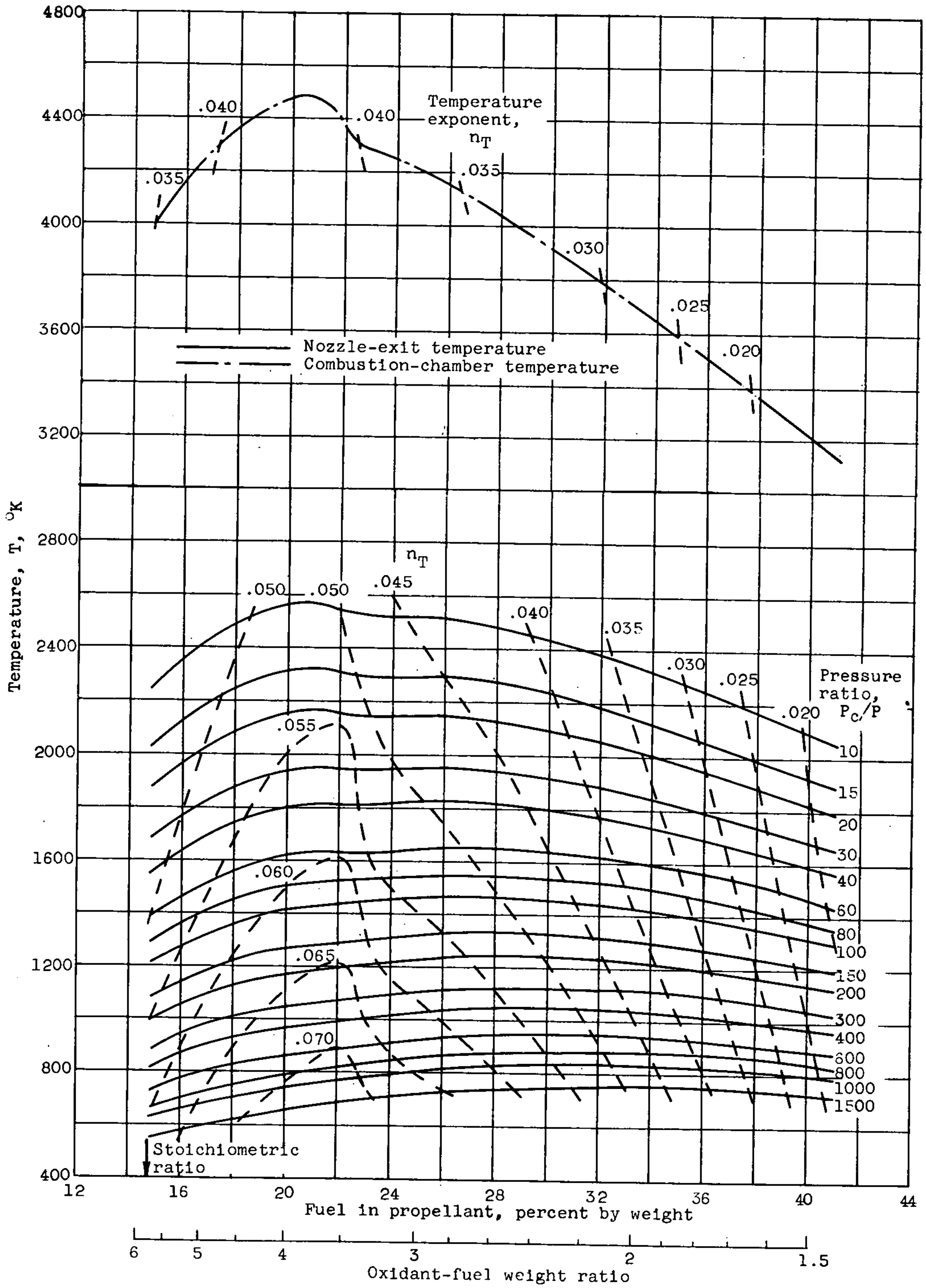
(a) Combustion-chamber pressure, 600 pounds per square inch absolute. Exponent n_I for use in equation $I = I_{600}\left(\frac{P_c}{600}\right)^{n_I}$.

Figure 1. - Theoretical specific impulse of JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



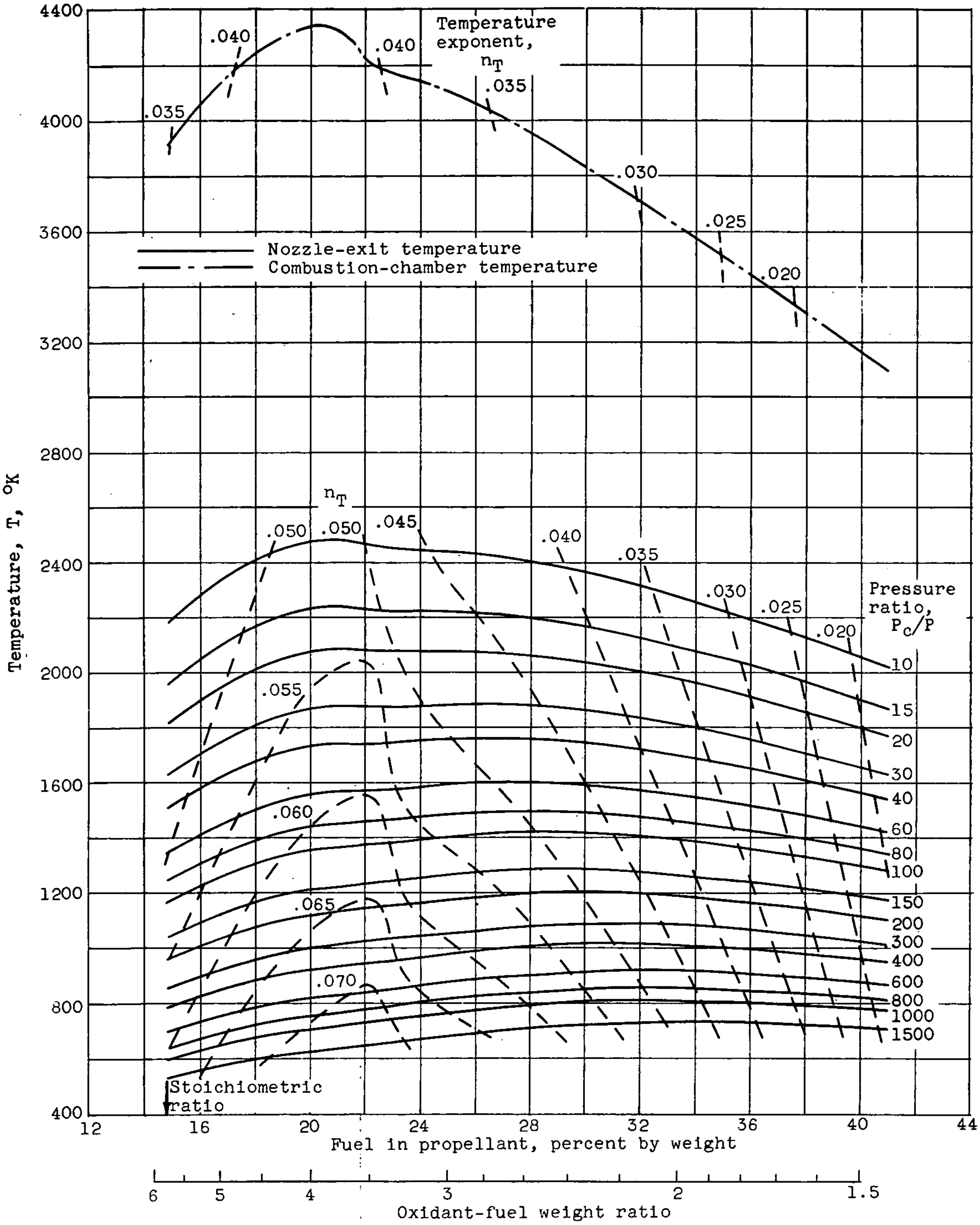
(b) Combustion-chamber pressure, 300 pounds per square inch absolute. Exponent n_I for use in equation $I = I_{300}\left(\frac{P_c}{300}\right)^{n_I}$.

Figure 1. - Concluded. Theoretical specific impulse of JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



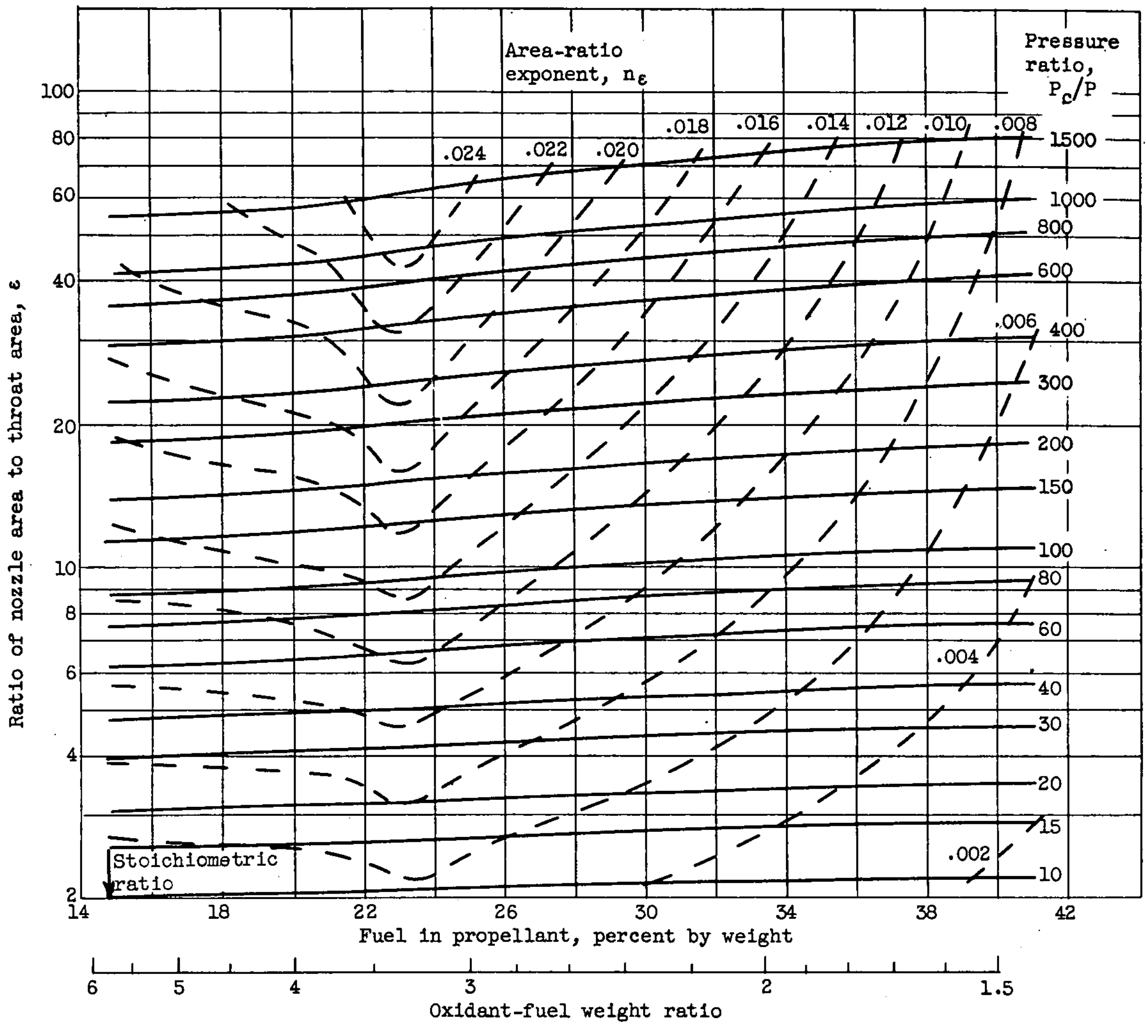
(a) Combustion-chamber pressure, 600 pounds per square inch absolute. Exponent n_T for use in equation $T = T_{600}\left(\frac{P_c}{600}\right)^{n_T}$.

Figure 2. - Theoretical combustion-chamber temperature and nozzle-exit temperature of JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



(b) Combustion-chamber pressure, 300 pounds per square inch absolute. Exponent n_T for use in equation $T = T_{300}\left(\frac{P_c}{300}\right)^{n_T}$.

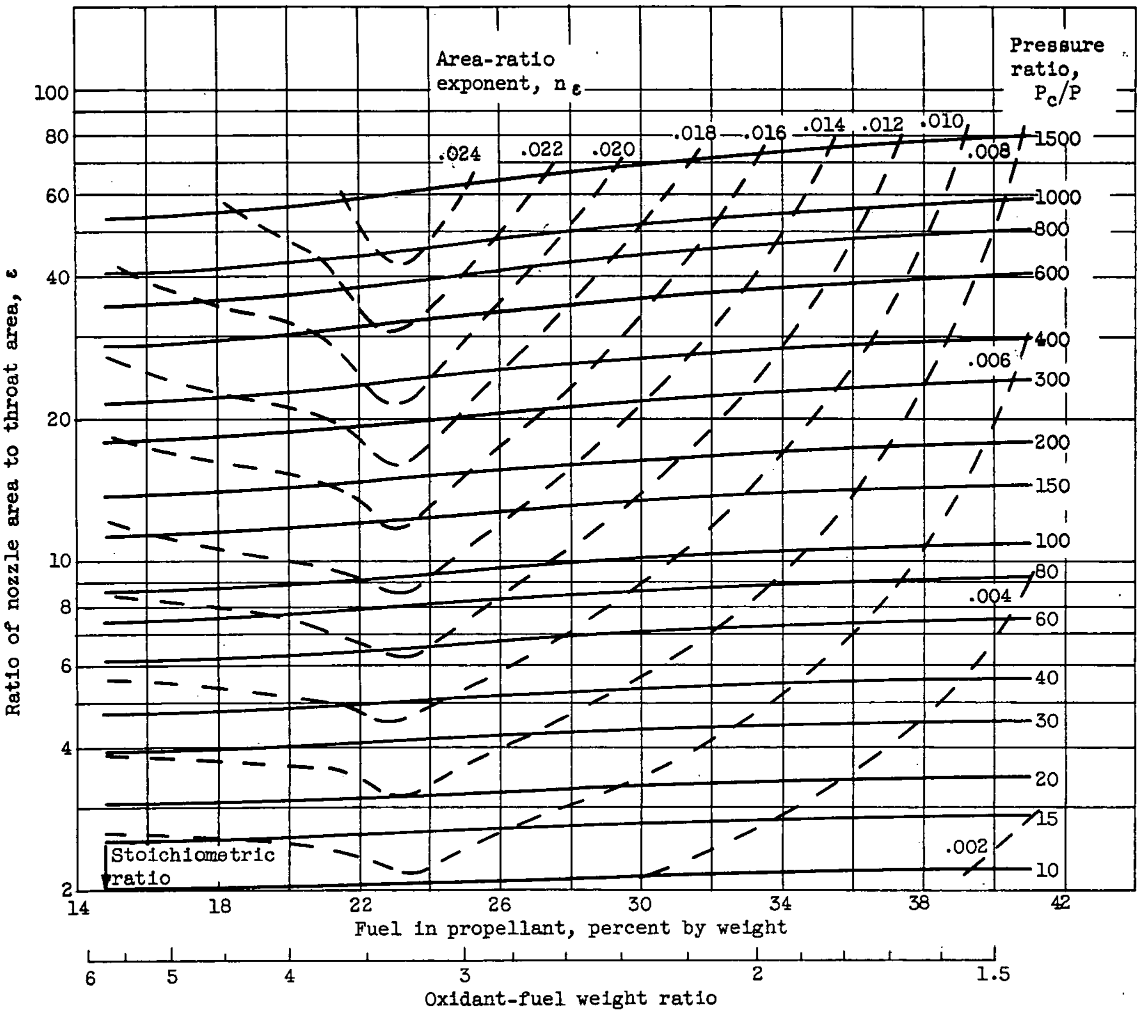
Figure 2. - Concluded. Theoretical combustion-chamber temperature and nozzle-exit temperature of JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Exponent n_ε for use in equation $\varepsilon = \varepsilon_{600}\left(\frac{P_c}{600}\right)^{n_\varepsilon}$.

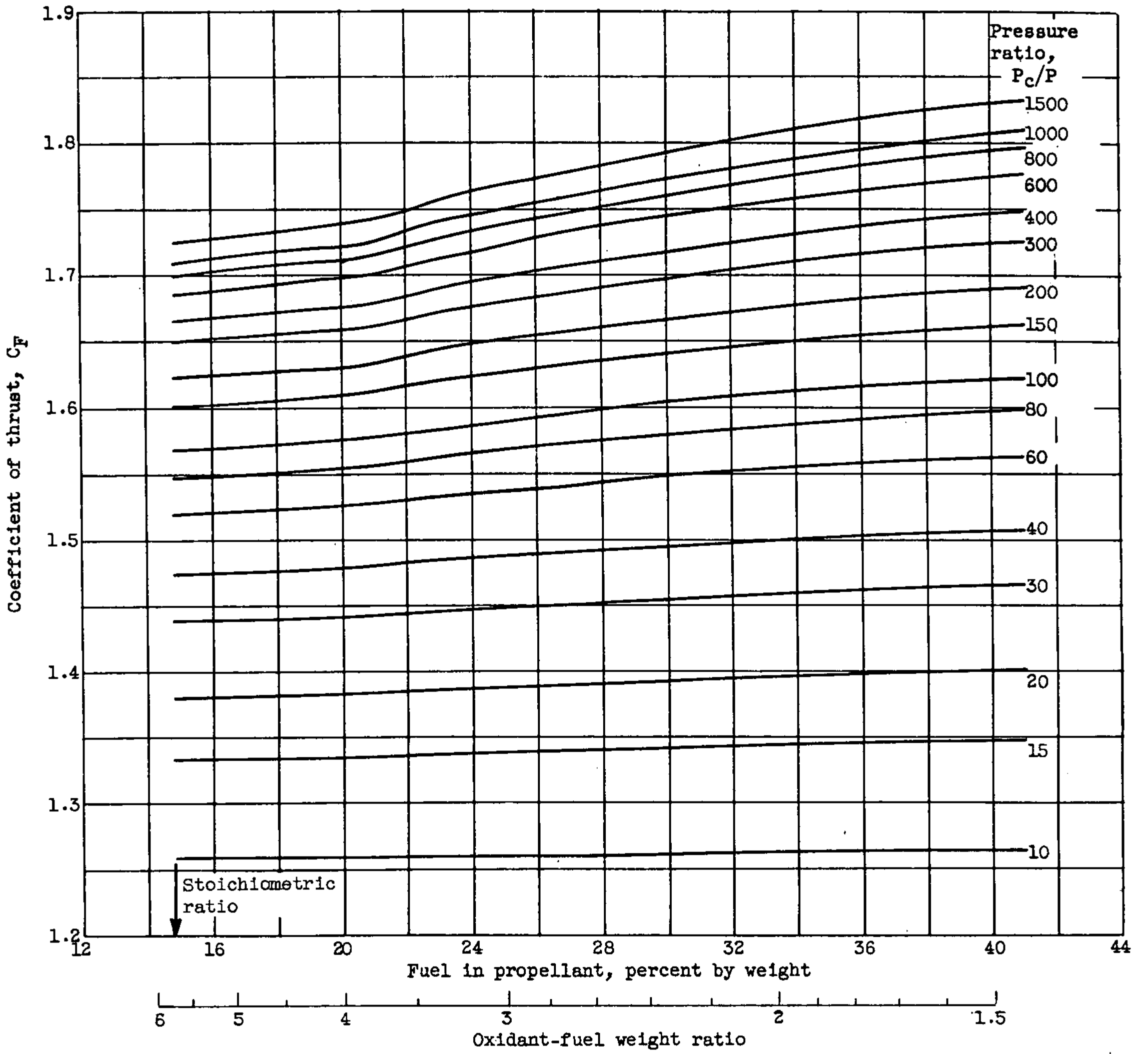
Figure 3. - Theoretical ratio of nozzle area to throat area for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

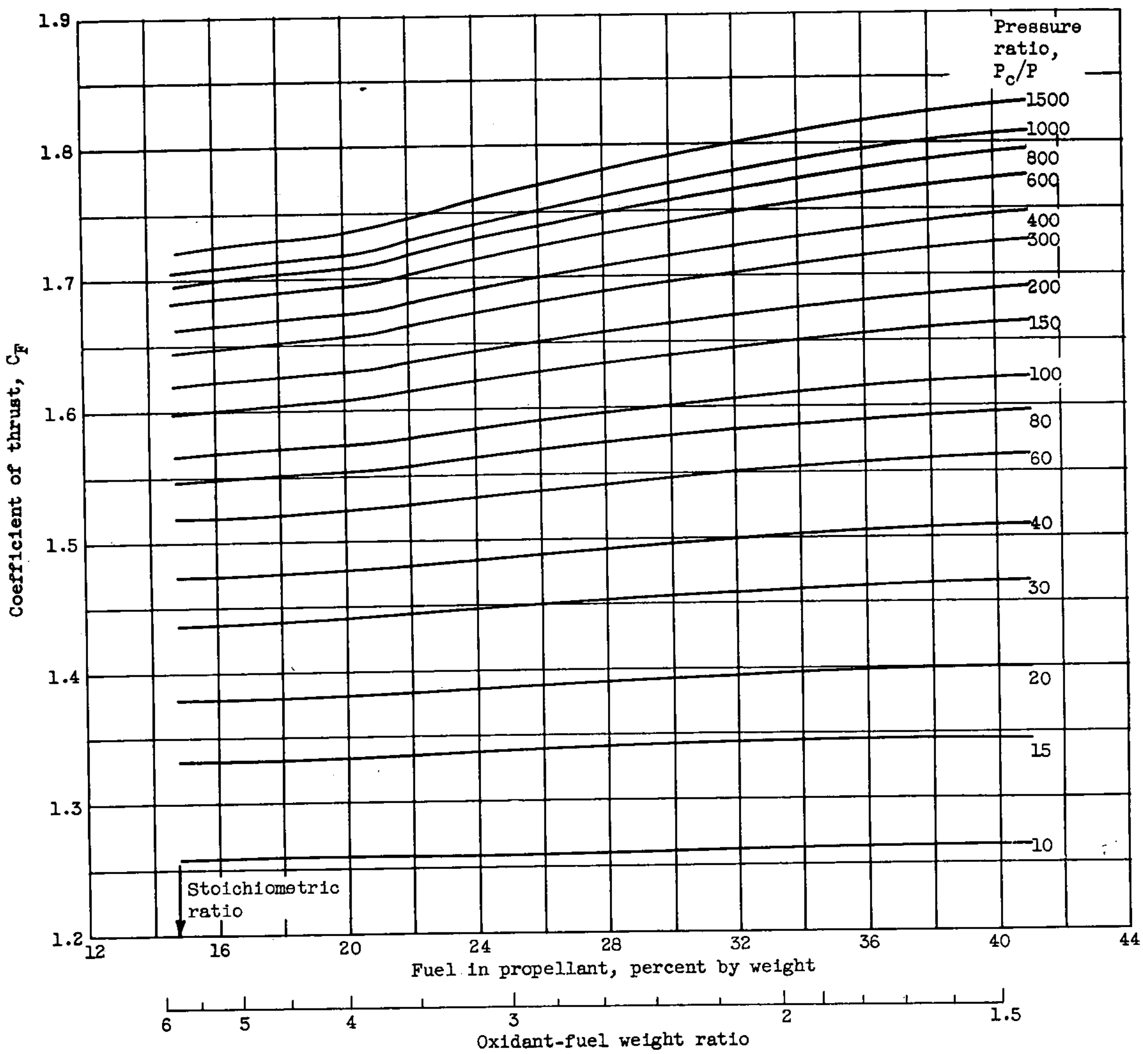
Exponent n_ε for use in equation $\varepsilon = \varepsilon_{300}\left(\frac{P_c}{300}\right)^{n_\varepsilon}$.

Figure 3. - Concluded. Theoretical ratio of nozzle area to throat area for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Figure 4. - Theoretical coefficient of thrust for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.



(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Figure 4. - Concluded. Theoretical coefficient of thrust for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion to pressure ratio indicated.

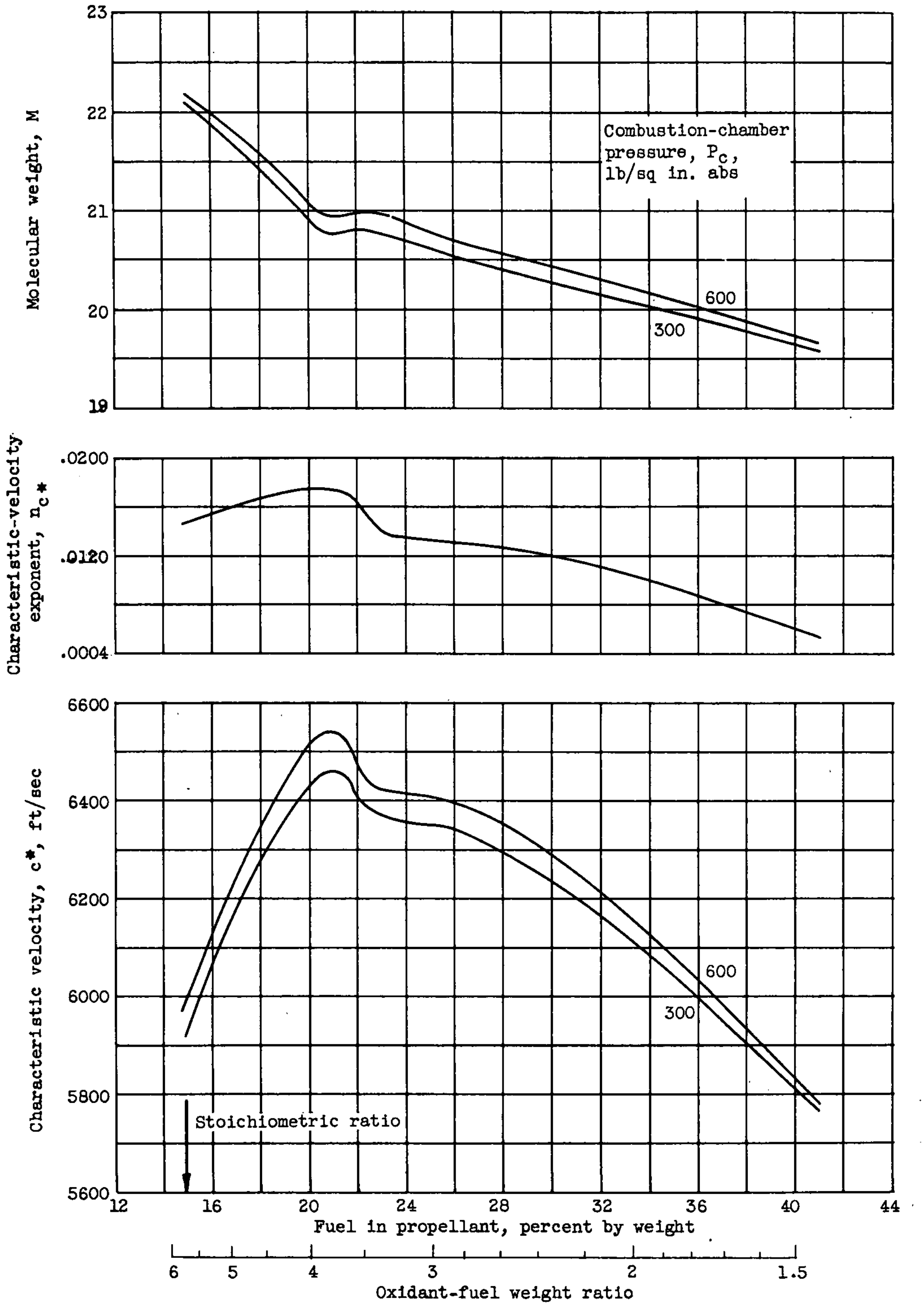


Figure 5. - Theoretical molecular weight, characteristic velocity, and exponent n_{c*} for use in equation $c^* = c^*_{300}\left(\frac{P_c}{300}\right)^{n_{c*}}$ for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Frozen composition during isentropic expansion from chamber pressure indicated.